

# Highlights from CMS

the path to discovery...



*Prof. Robin D. Erbacher – U.C. Davis*

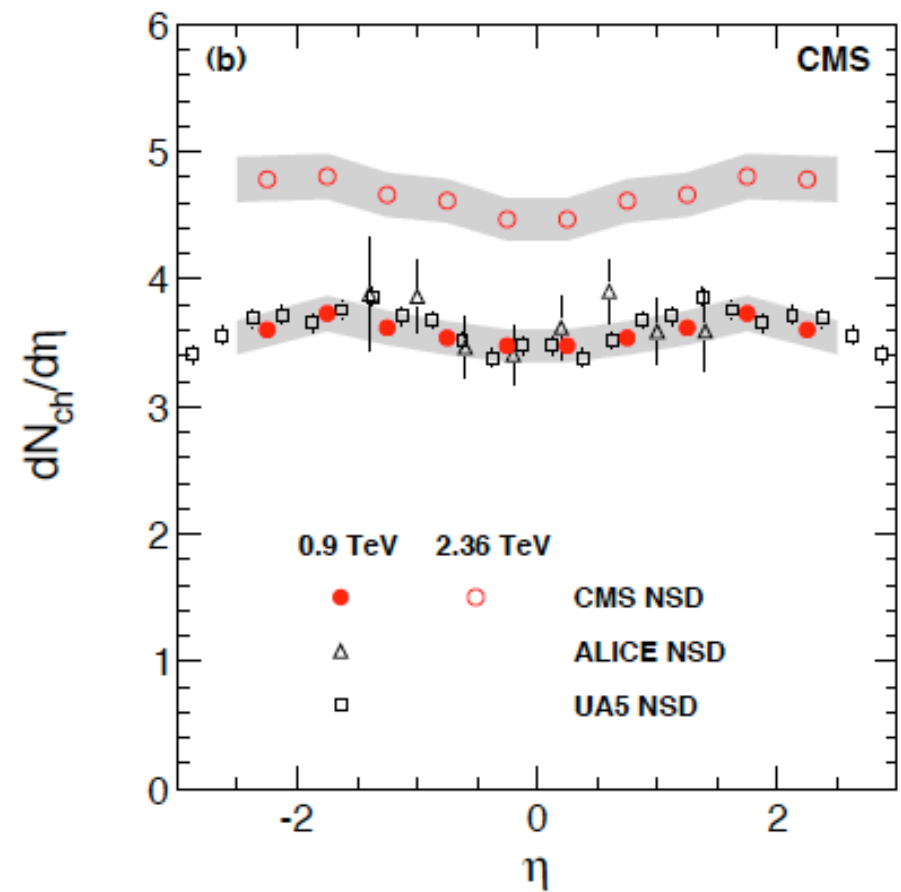
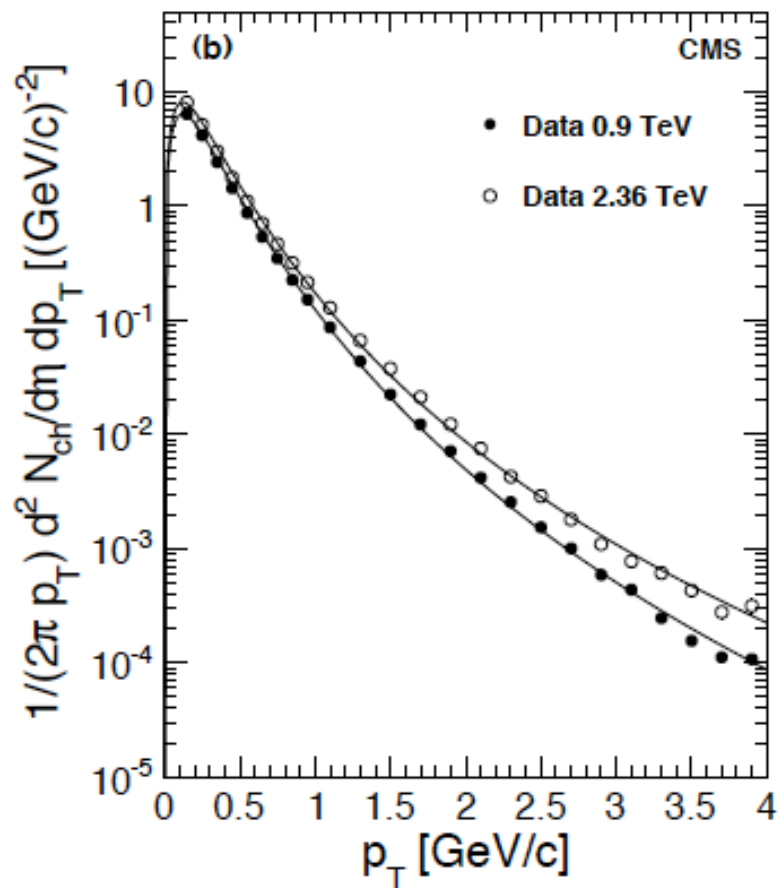
*Brookhaven Forum – “A Space-Time Odyssey” – May 26, 2010*

# Data through last year...

- CRAFT '08/'09 + other ~ 1 B cosmic events  
➡ 23 performance papers to JINST
- 900 GeV (Nov 2009) -- 300k events  
➡ first physics paper, lots of calibrations
- 2.36 TeV (Dec 2009) -- 20k events  
➡ first peek at high energies

# First Publication from CMS!

Inclusive particle  $p_T$ , and pseudorapidity at 900 GeV and 2.36 TeV



JHEP 02 (2010) 041

# Ramping up for high energy collisions...

- CRAFT (end 2008) -- 600k events  
➔ 23 performance papers to JINST
- 900 GeV (Nov 2009) -- 300k events  
➔ first physics paper, lots of calibrations
- 2.36 TeV (Dec 2009) -- 20k events  
➔ first peek at high energies

The big event: March 30, 2010 -- 7 TeV collisions!



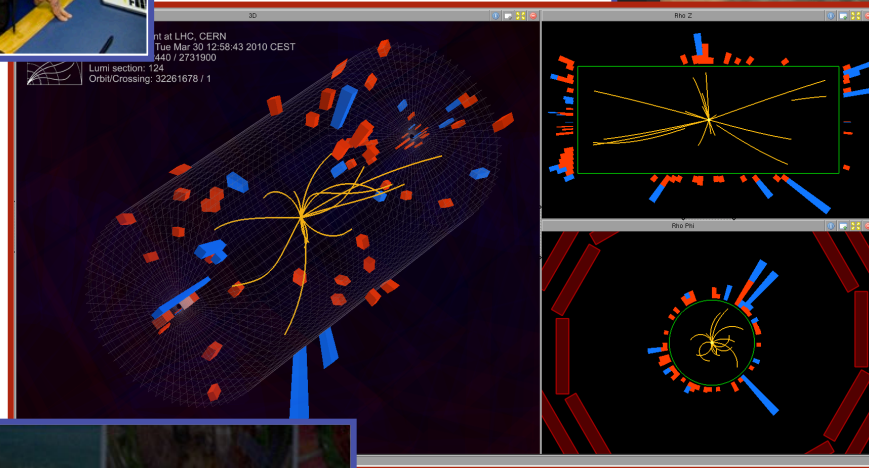
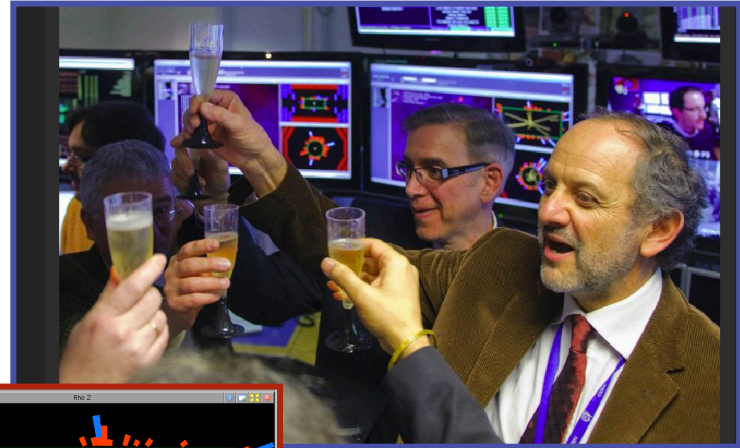
# First 7 TeV Collisions



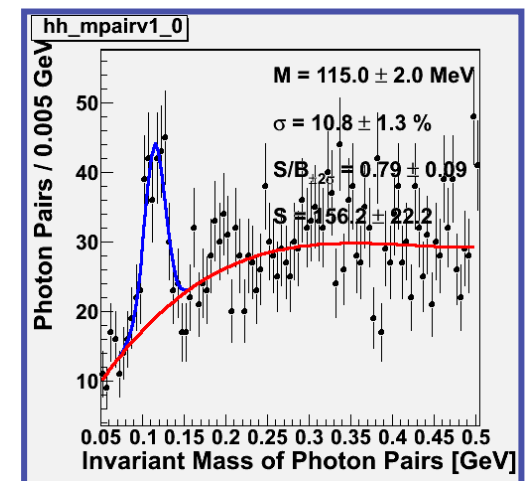
Point 5 Control Room - March 30, 2010



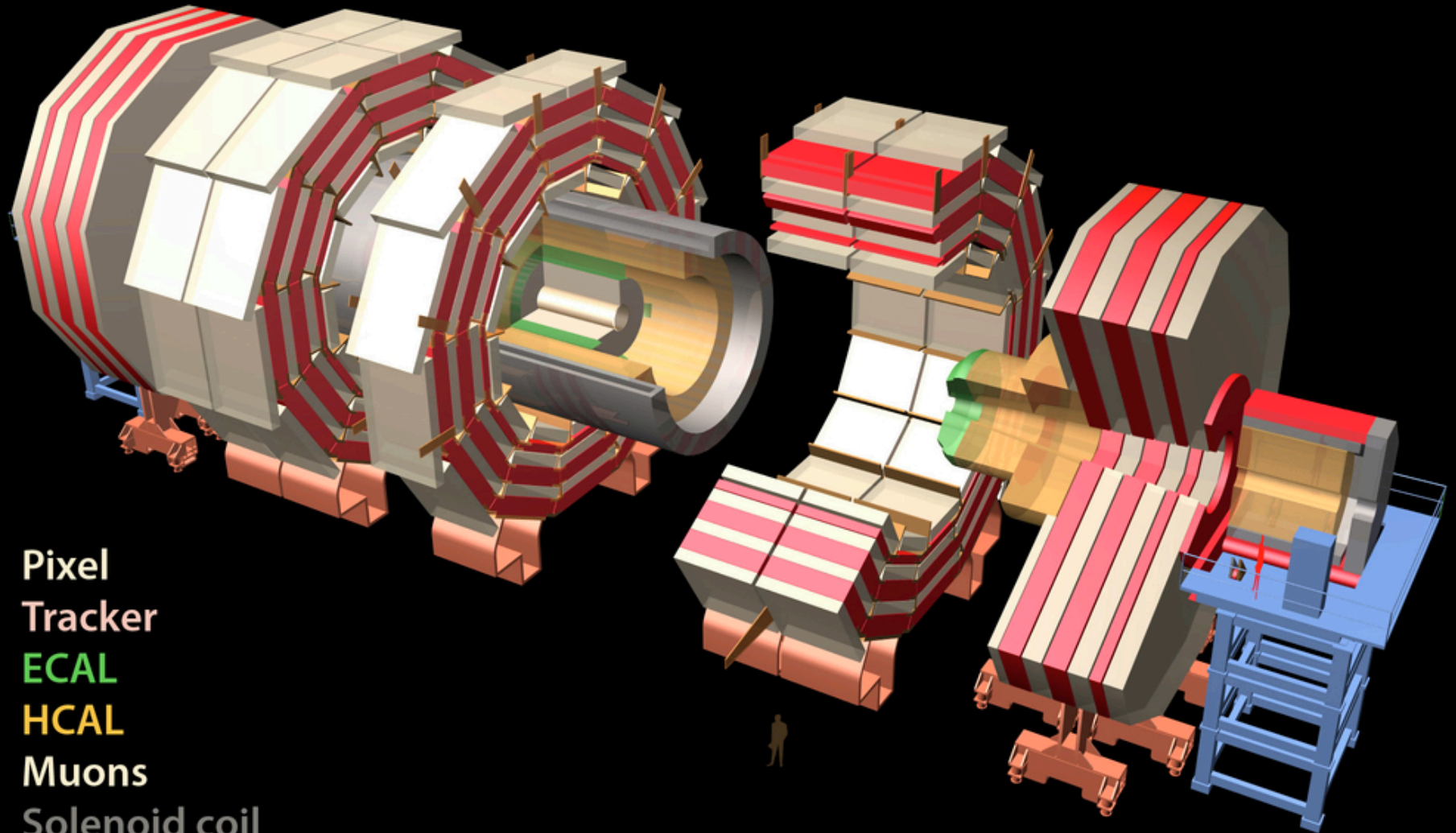
# Success!



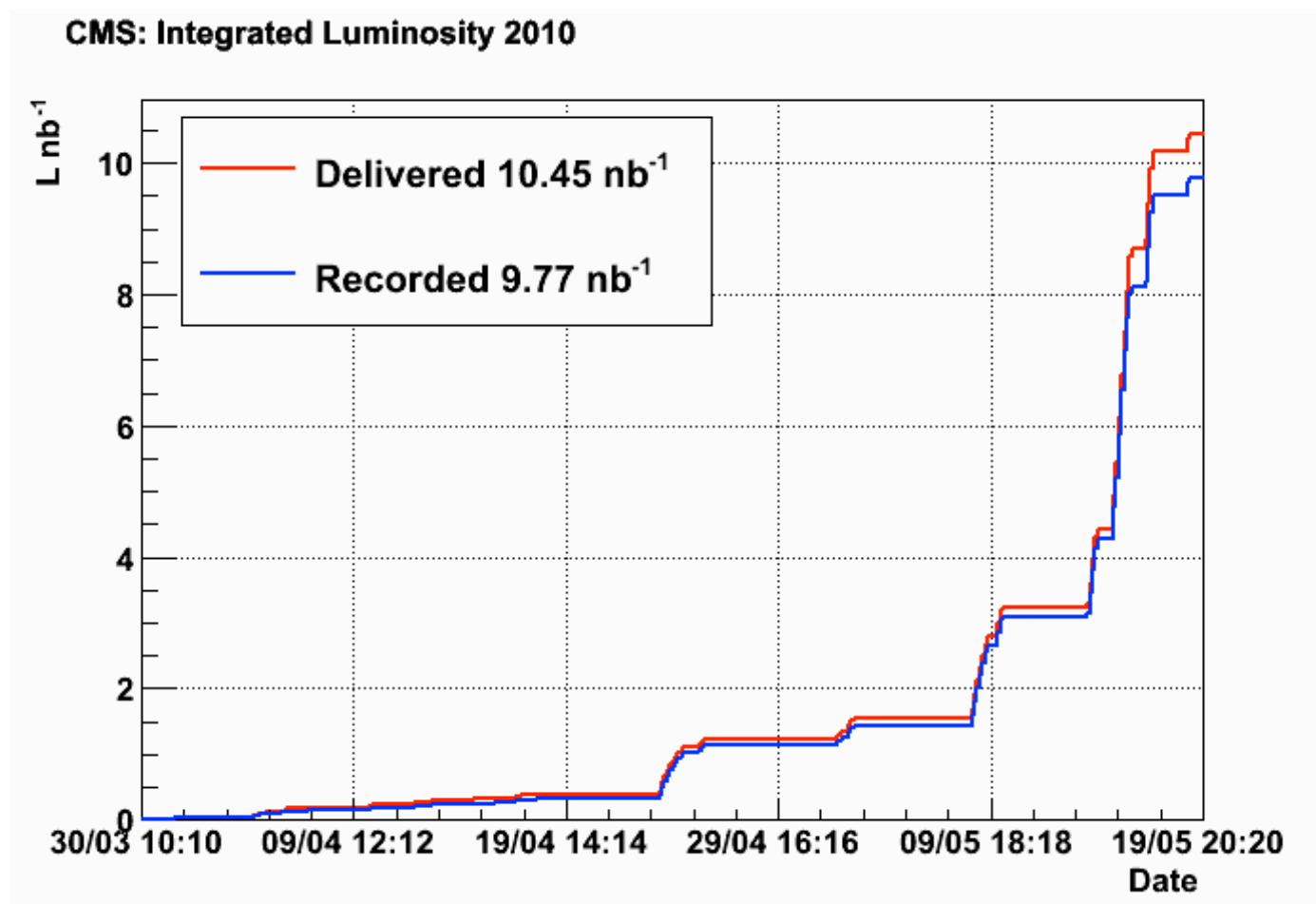
within 5  
minutes...



# The LHC experiments are at last collecting high energy data!



# Luminosity profile since March



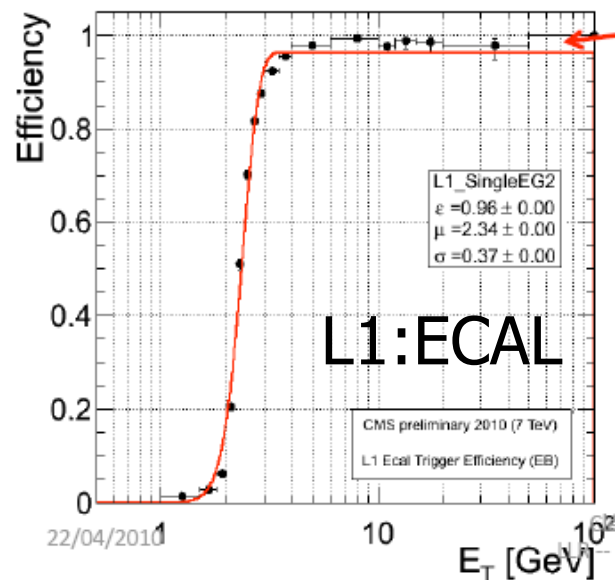
Data-taking efficiency quite good even at start

# Theorists v. Experimentalists

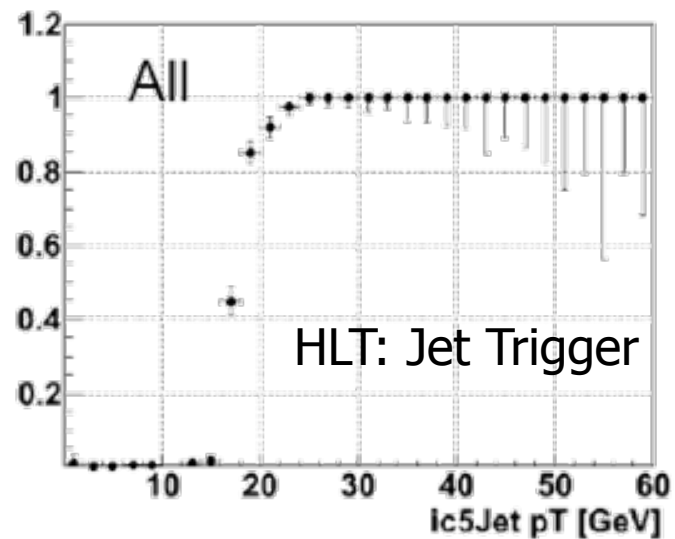
- Theorists want to know...
  - Now that we have collisions, how will we know if the new physics is SUSY?
  - How will we determine the full spectrum and mass scale? The Lagrangian?
- Experimentalists are thinking...
  - Now that we have collisions: Is there a leak? Does the trigger work?
  - How much noise is there?
  - What is the actual size of the QCD backgrounds?
  - How will we know whether its new physics, or SM plus mistakes on the tails of the distributions?



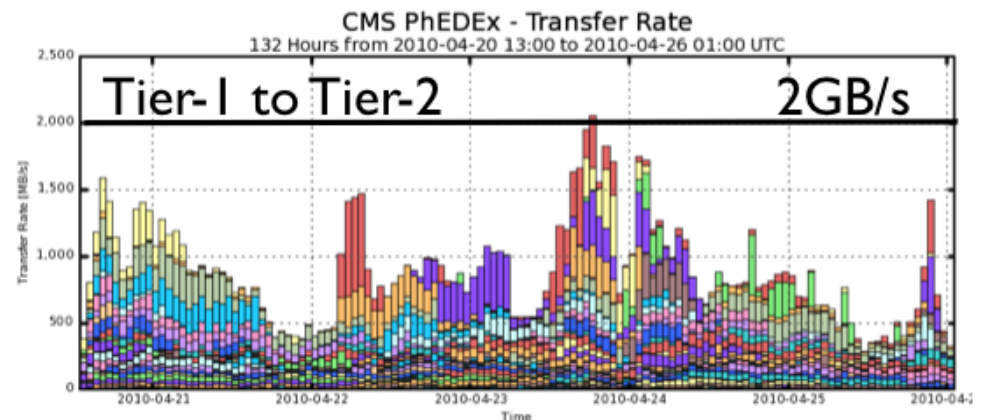
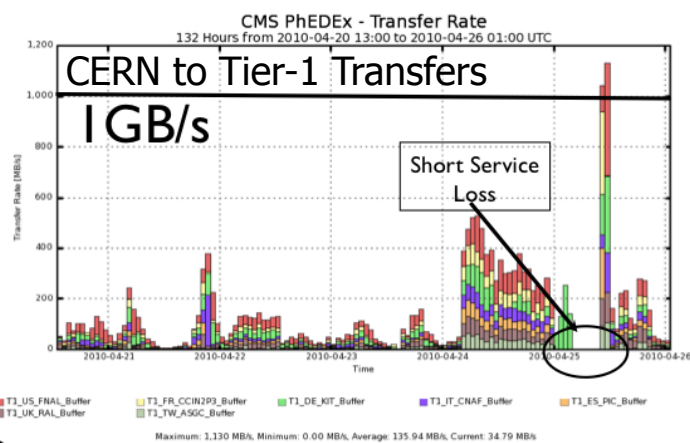
# Triggers and Computing



Level I Triggers  
quite efficient

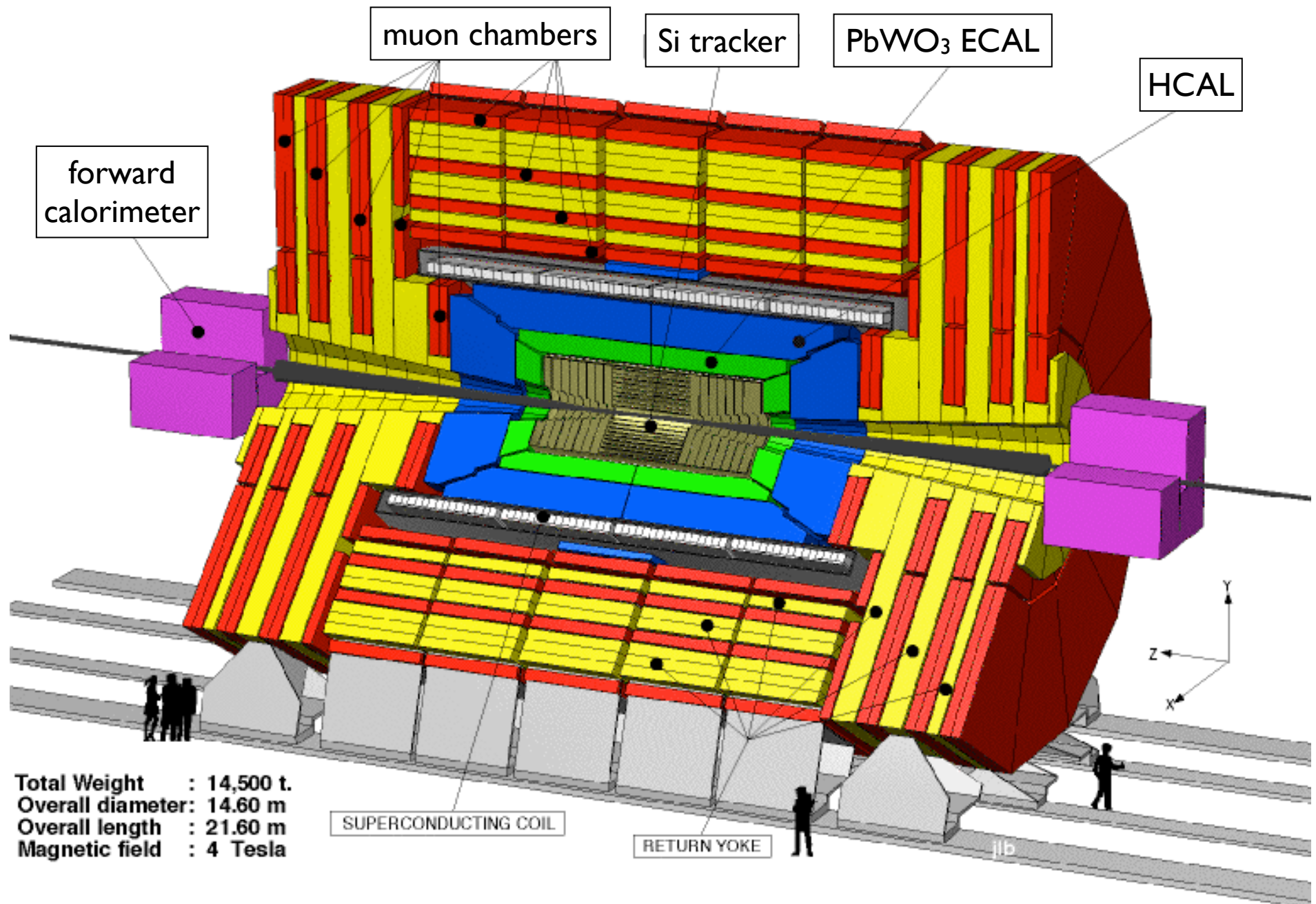


High Level Trigger menus  
performing well

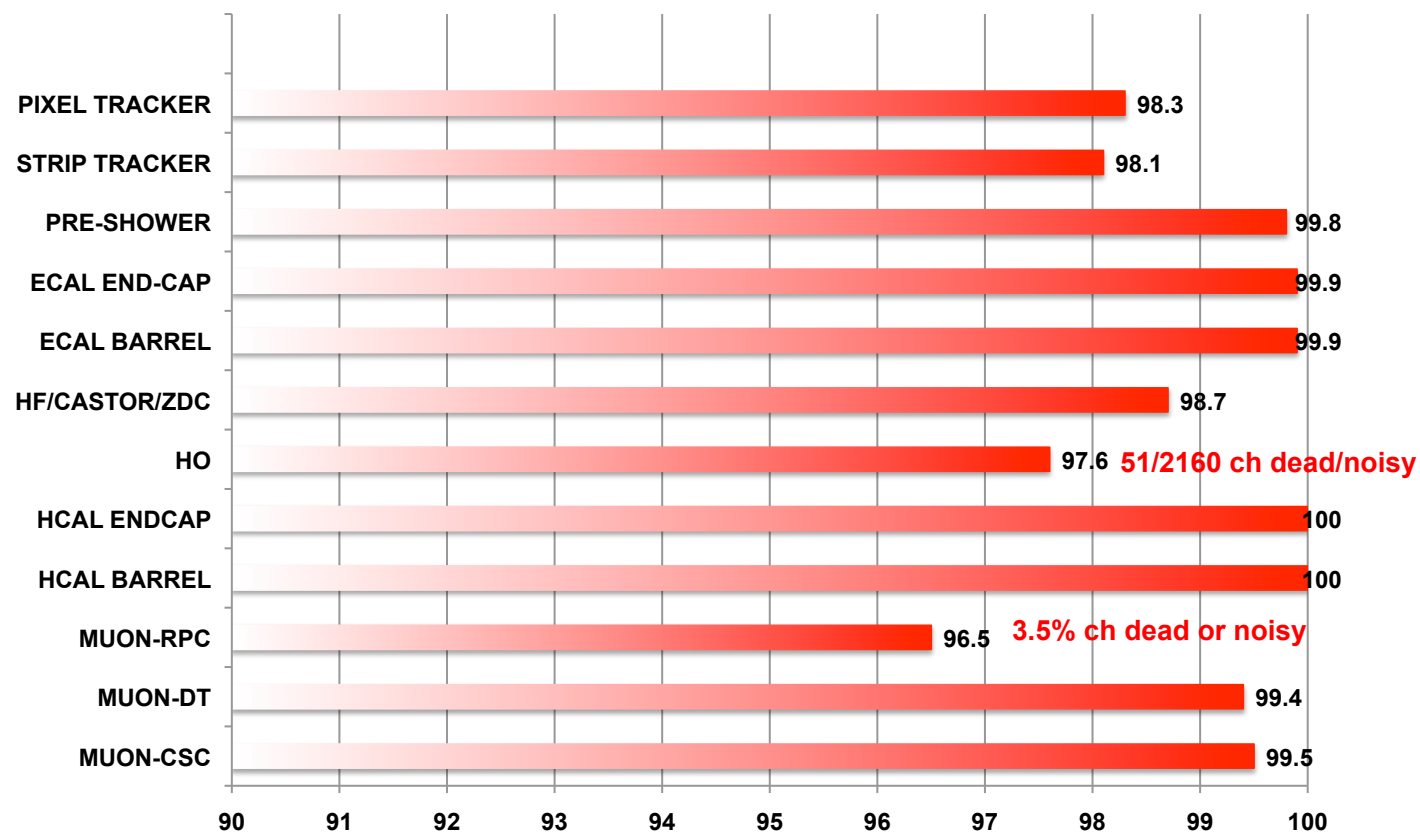


Tier 1 and Tier 2 centers performing reliably

# CMS is performing well!



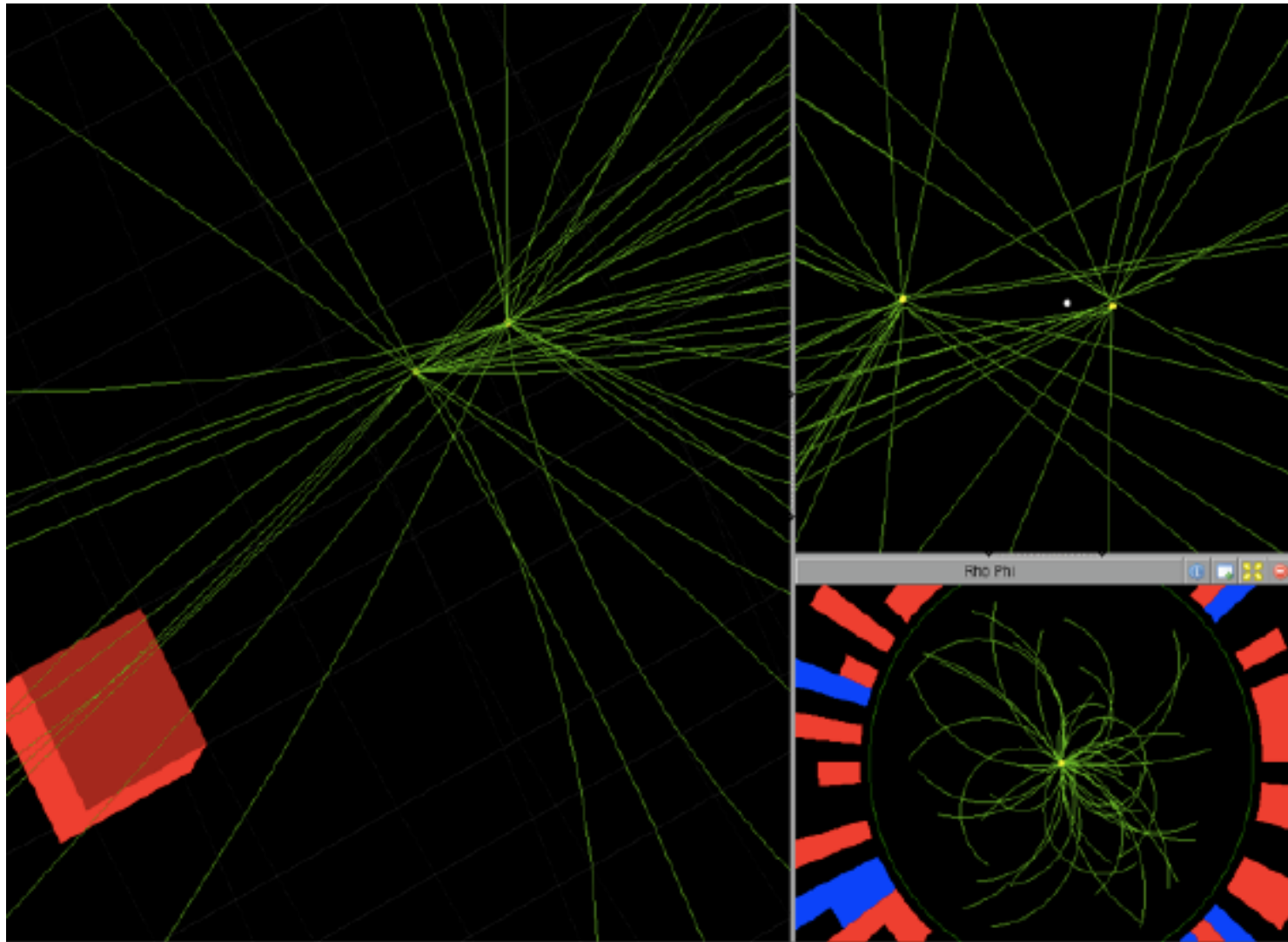
# CMS operation: start of 7 TeV



Already since improved: Eg- RPCs 98.8% live by May 21.



# Low luminosity but...



Two vertex event. Pile-up seen ( $>0.5\%$ ) already at start. Currently 10%, soon 100%! Will be an issue, but we're ready.

# Squeezed stable beams



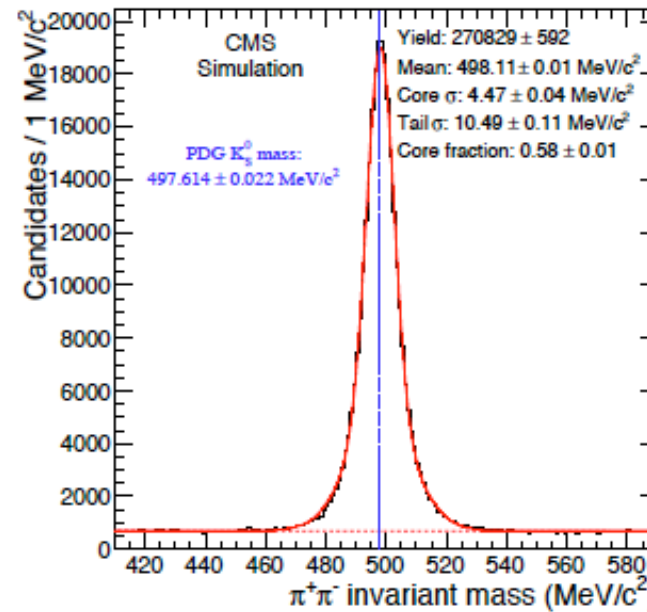
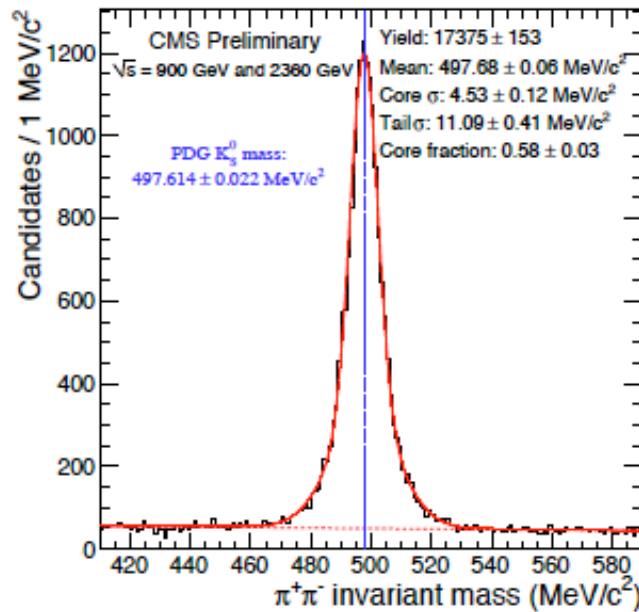
May 1-2: Squeezed, stable beams (30 hours).  
Luminosity  $> 1 \times 10^{29} \text{ cm}^{-2}\text{s}^{-1}$ , achieved Monday!

# Tracker Performance

data

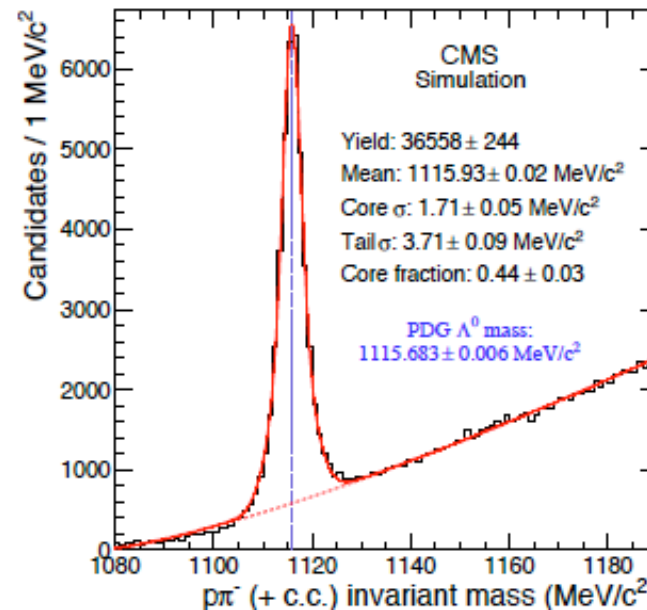
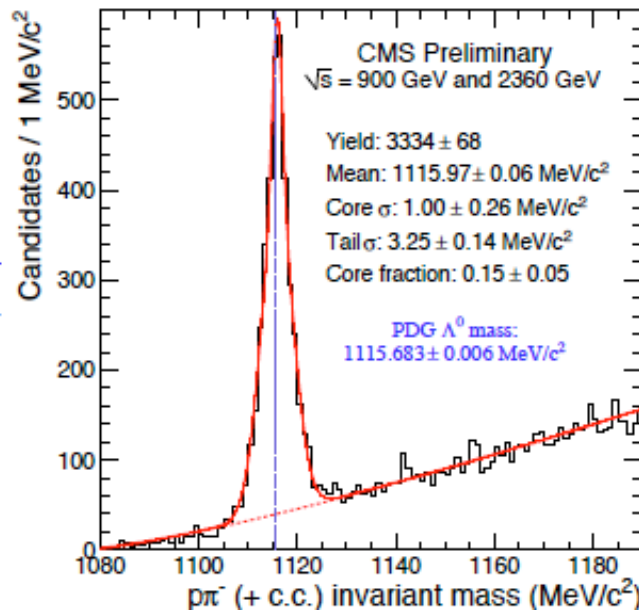
simulation

$K_s$

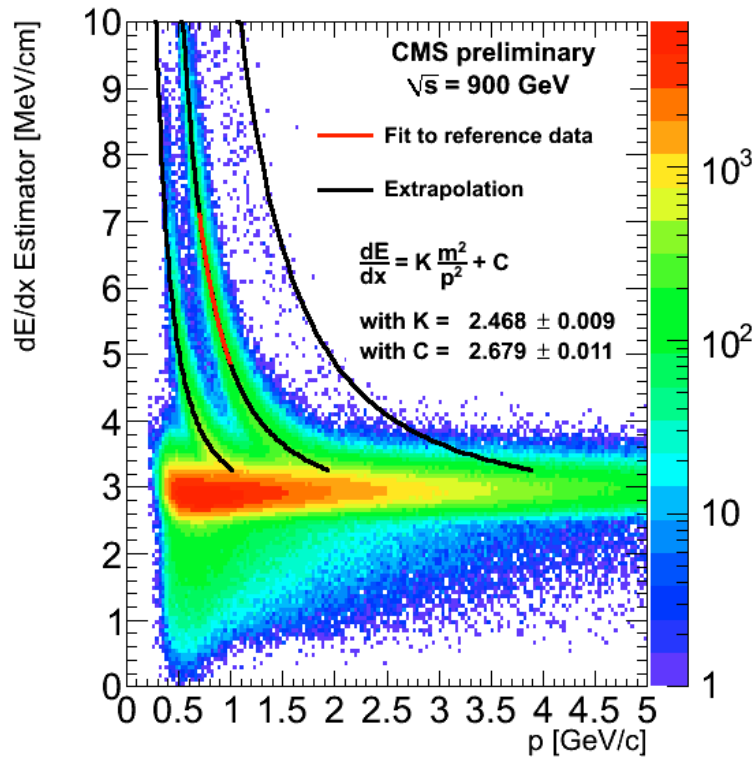


Pixels and strips are doing very well

$\Lambda$

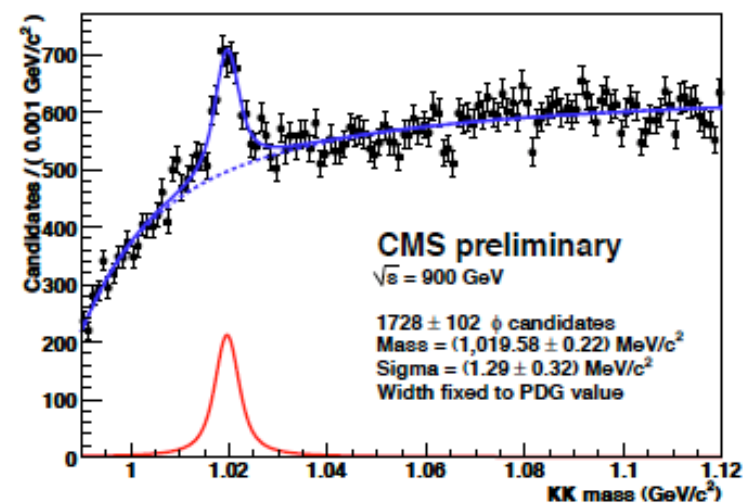
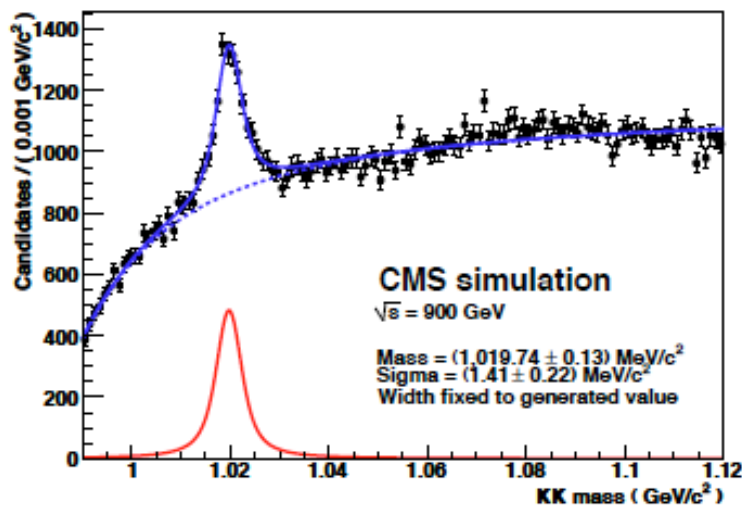


# Tracking: dE/dx



Use large sampling  
 along tracks for particle  
 ID with dE/dx

$\phi \rightarrow KK$

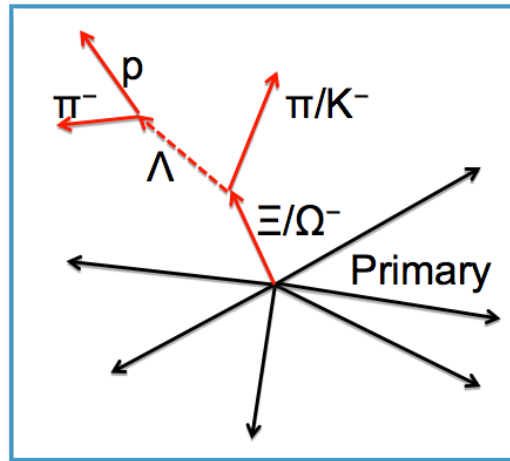


# More Resonances

$$\Omega^\pm \rightarrow \Lambda K^\pm$$

$\Lambda K^-$  or anti-  $\Lambda K^+$   
invariant mass

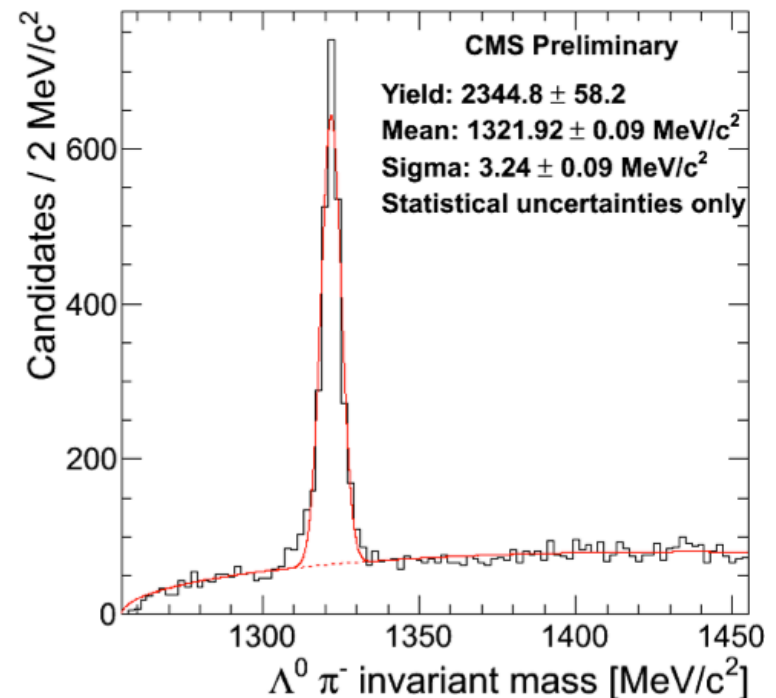
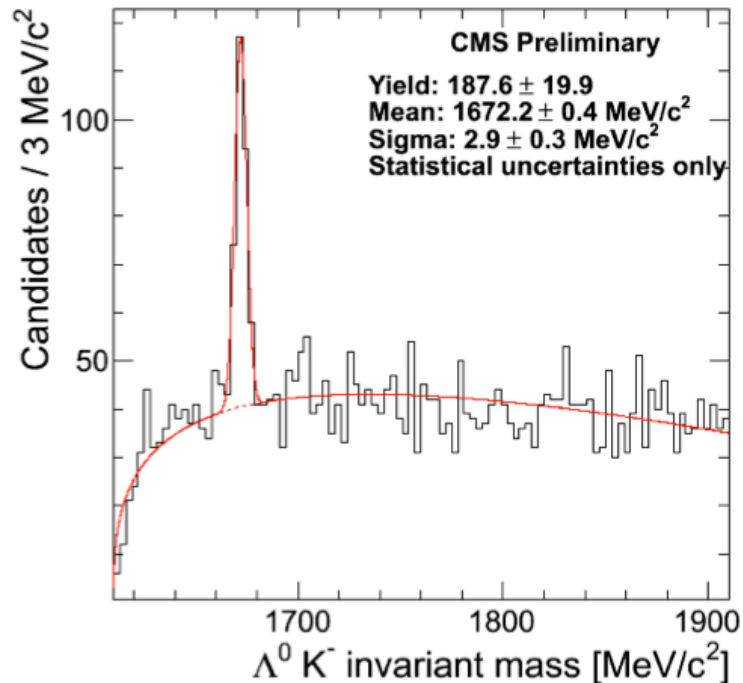
- combinations fit to a common vertex



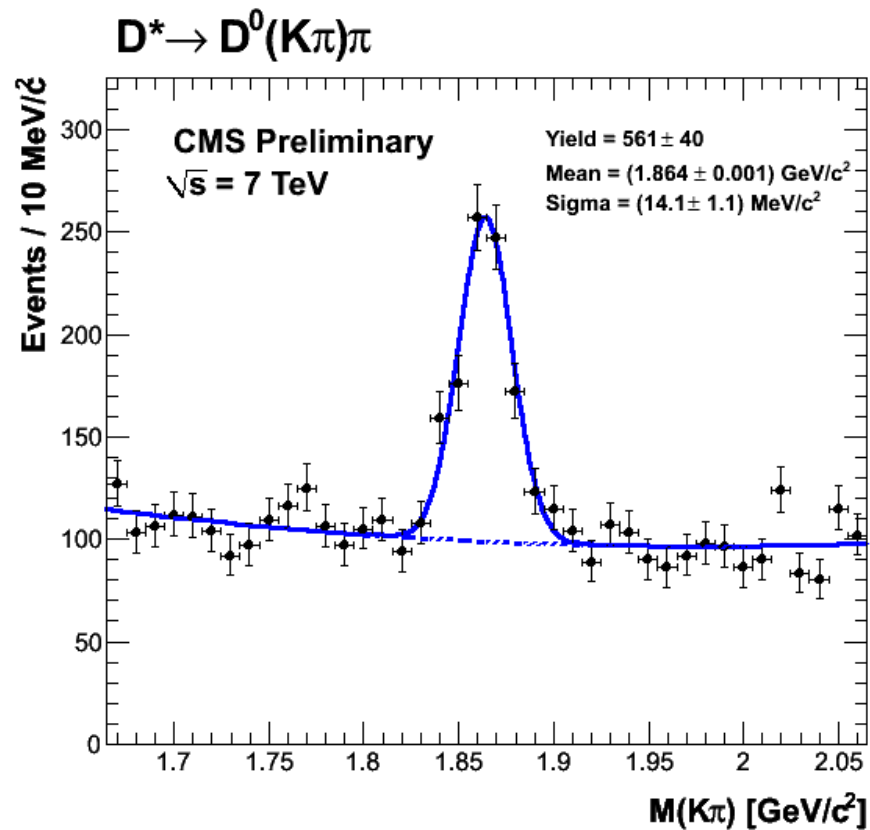
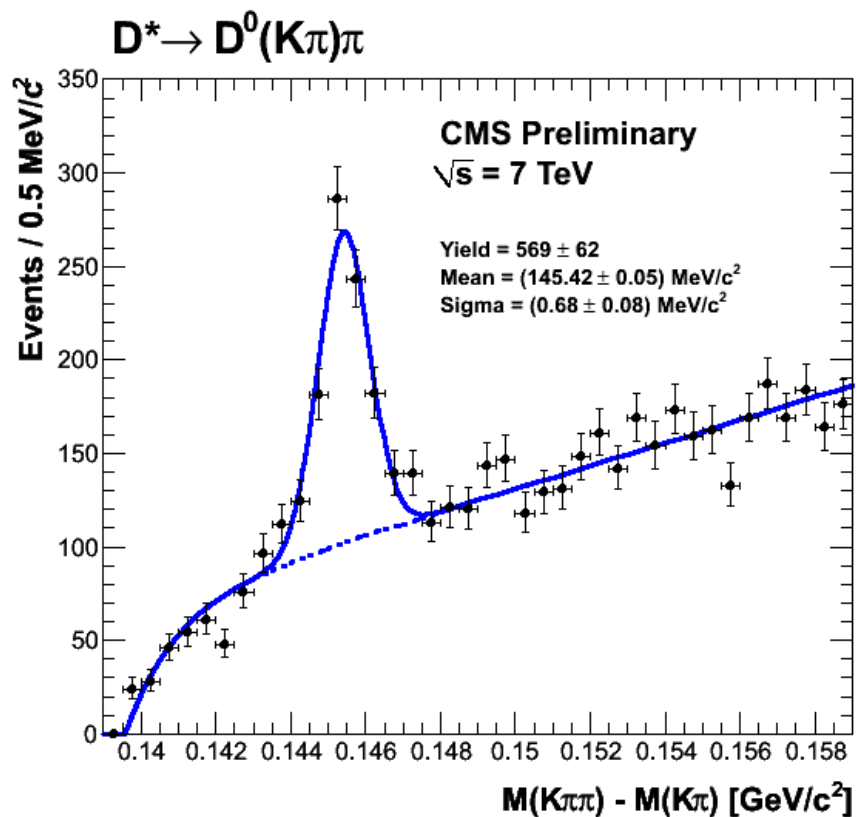
$$\Xi^\pm \rightarrow \Lambda \pi^\pm$$

$\Lambda \pi$  invariant mass

- tracks displaced from primary vertex
- common displaced vertex



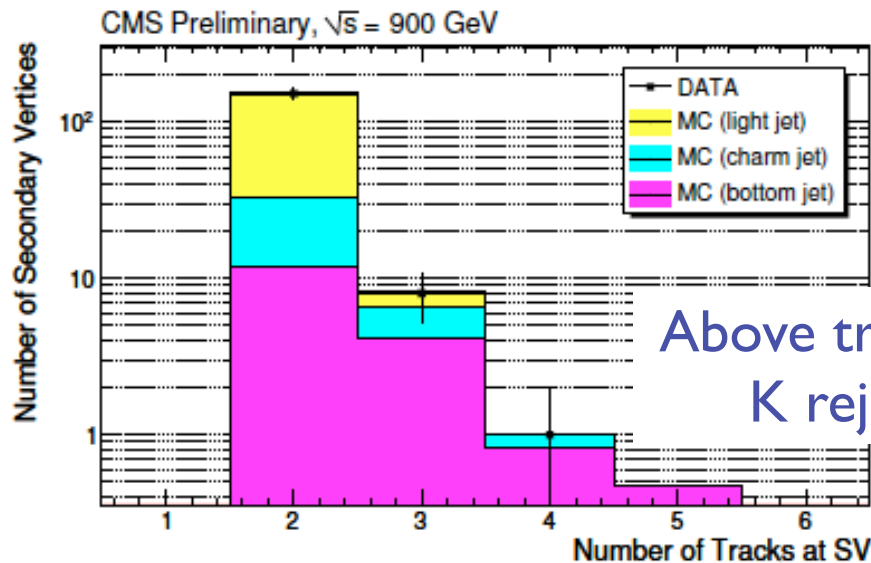
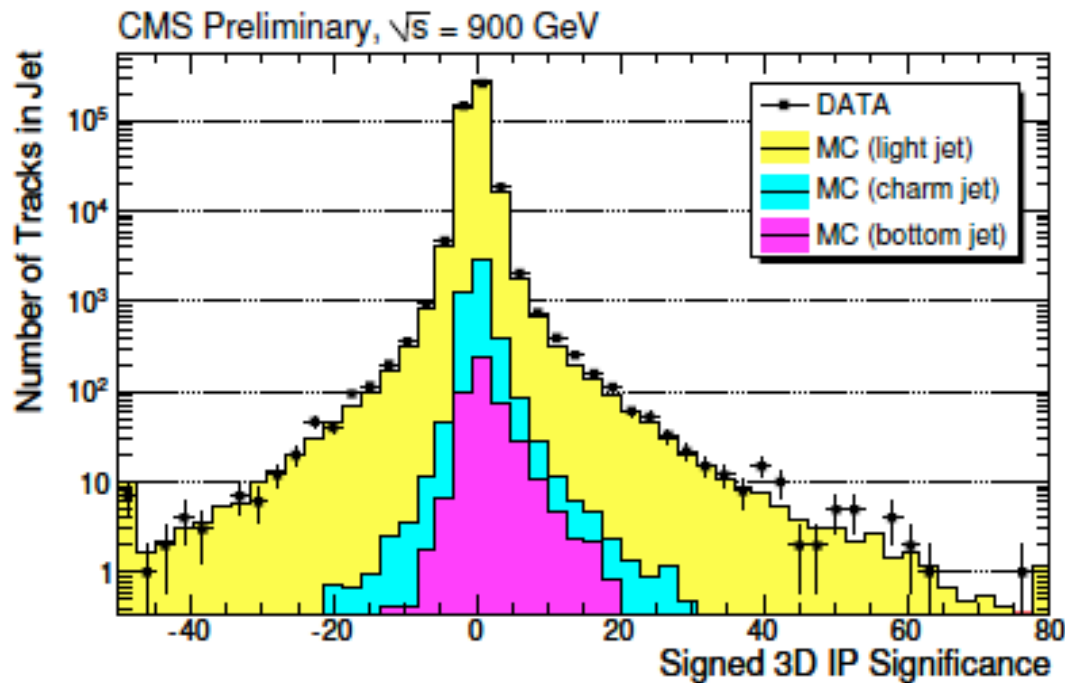
# $D^*$ in 7 TeV data!



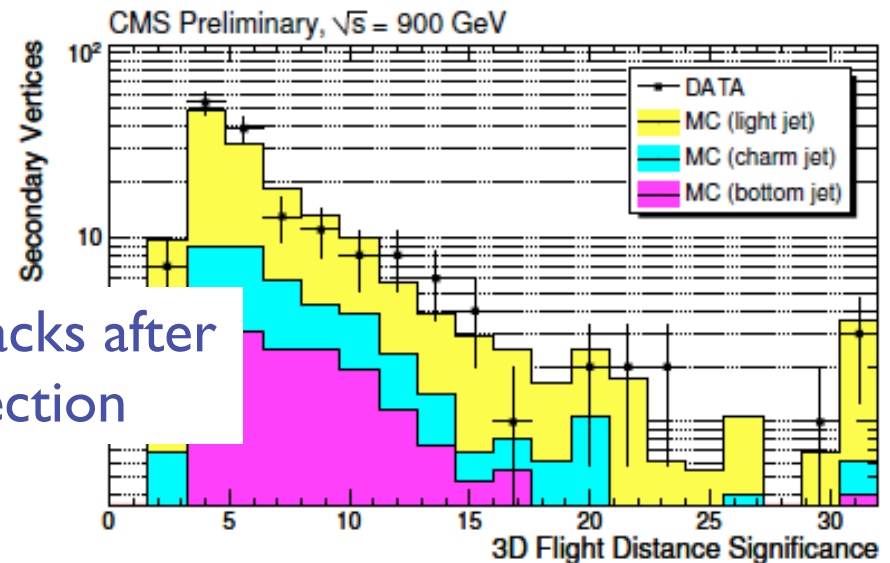
See very clean  $D^* \rightarrow D^0\pi$ ,  $D^0 \rightarrow K\pi$

# Secondary Vertices: b-tagging

(900 GeV) Basic b-tagging variables look good v. sim. Need more tuning with new data.

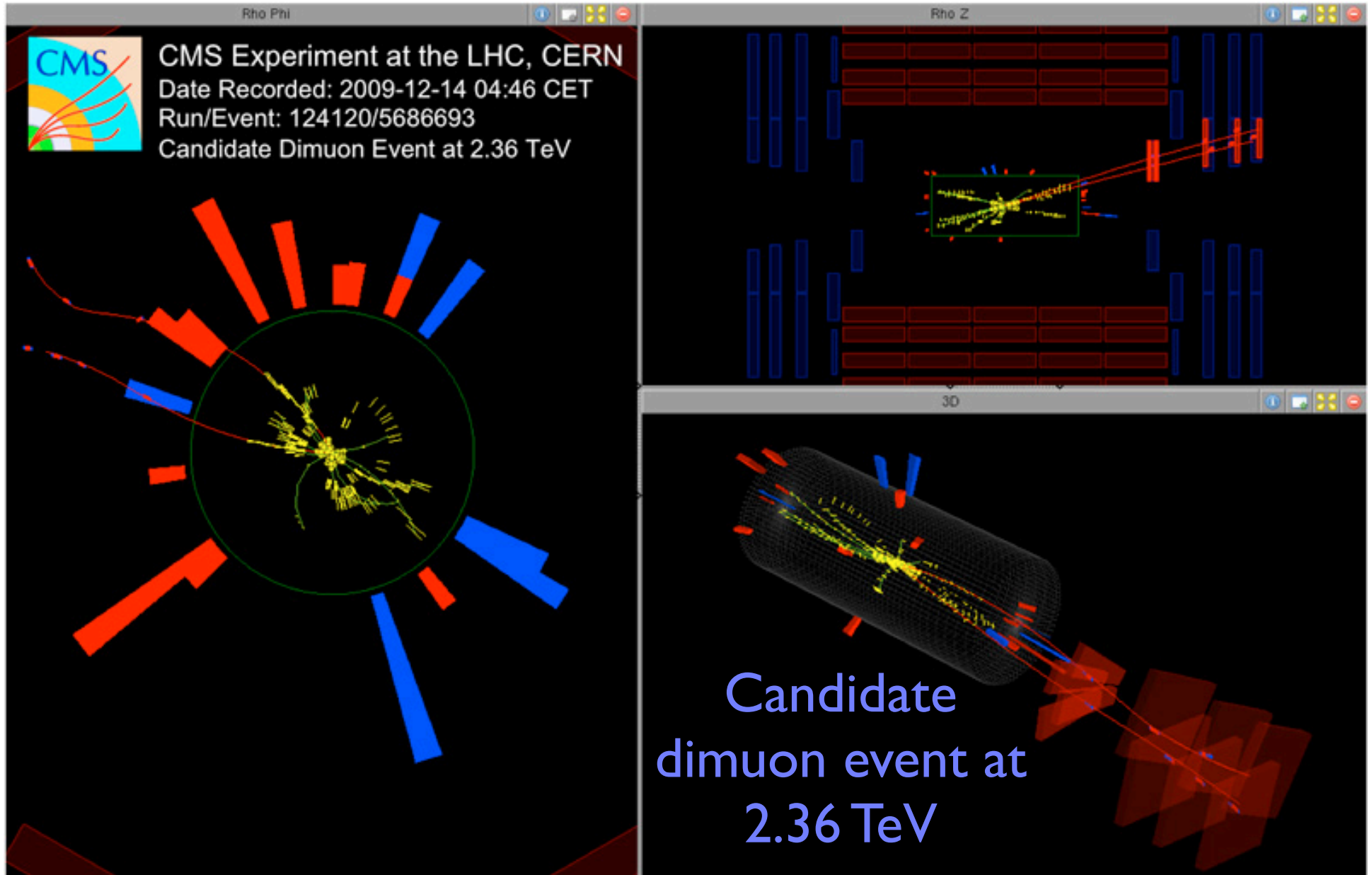


Above tracks after  
K rejection





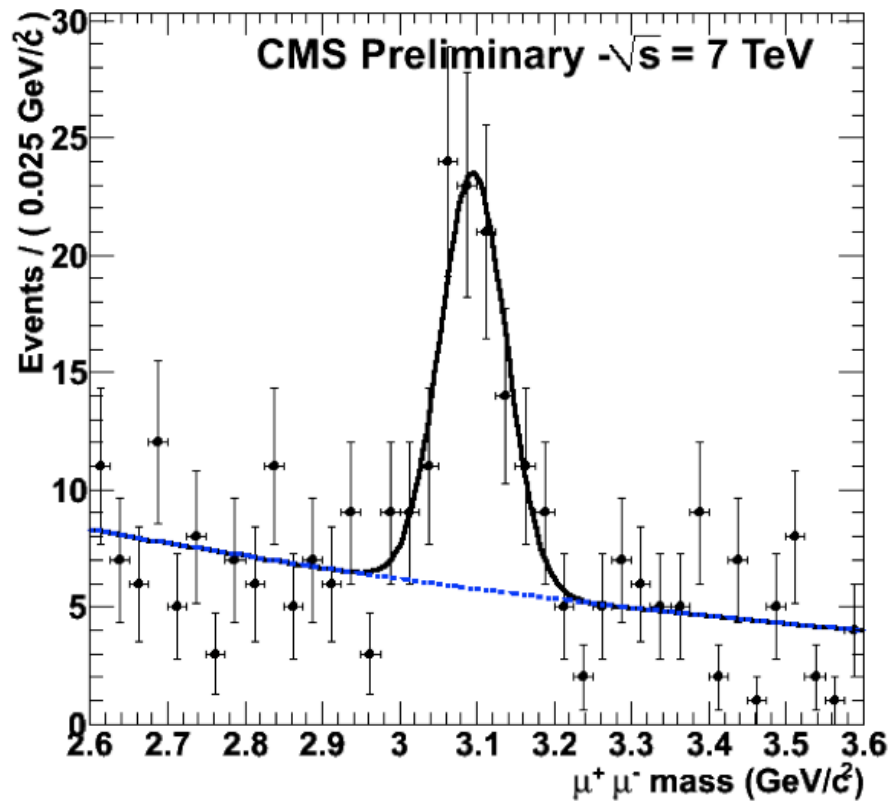
# Compact MUON Solenoid



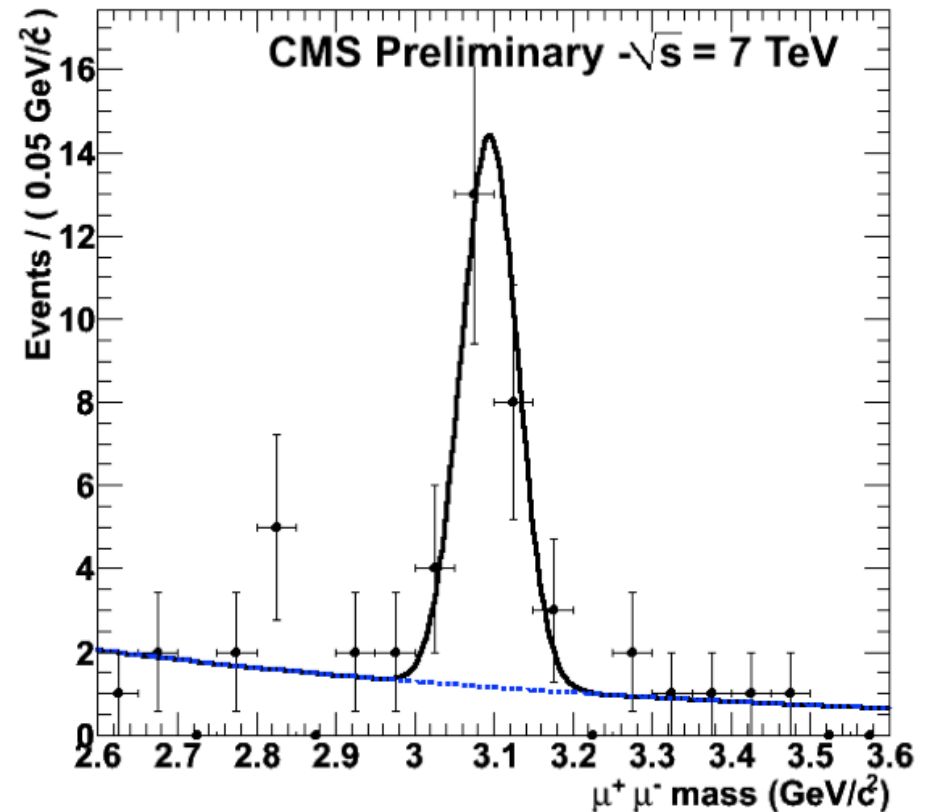


# $J/\Psi$ decaying to muons

Clear  $J/\Psi$  signal in the data.



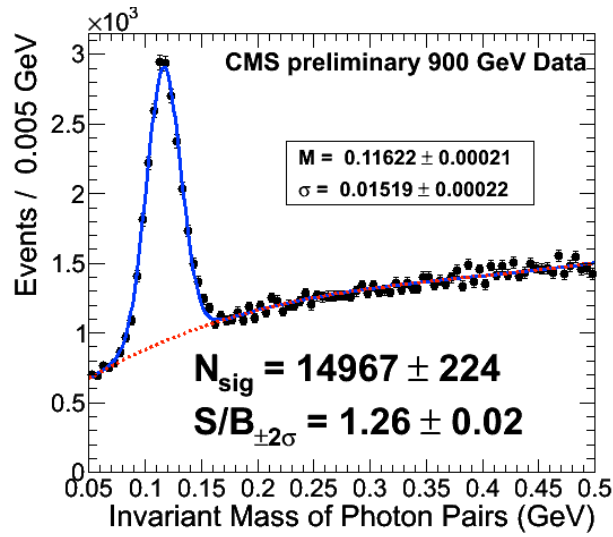
Loose:  $76 \pm 12$  signal events



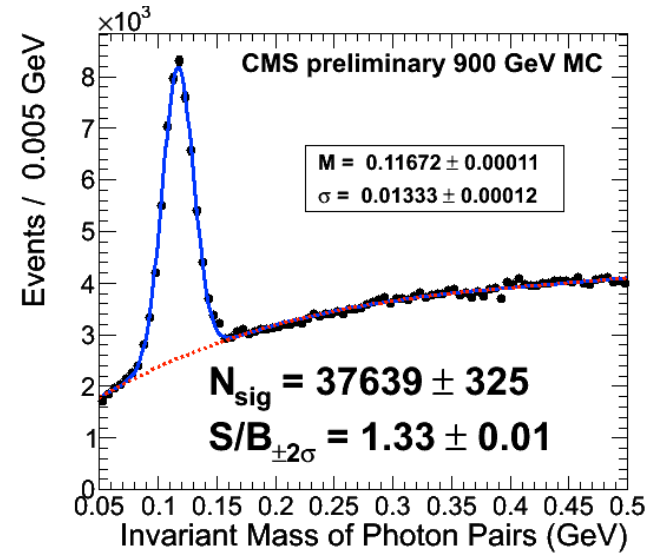
Tight:  $24 \pm 5$  signal events

# Electromagnetic Calorimeter

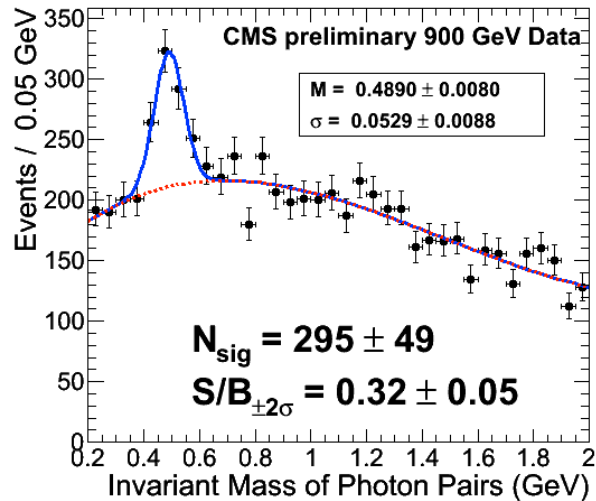
$\pi^0$   
data



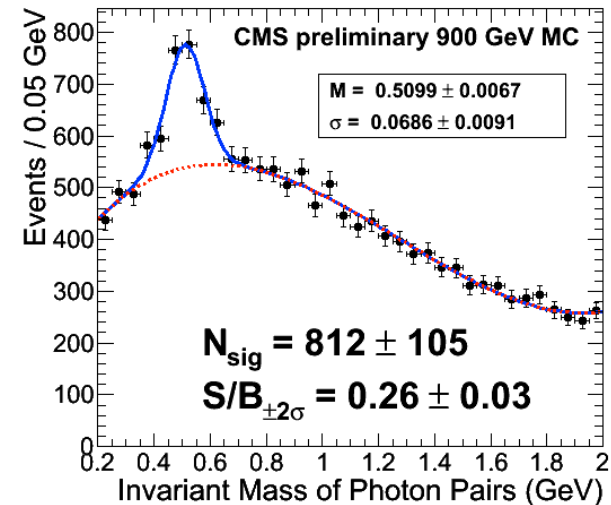
$\pi^0$   
sim



$\eta$   
data

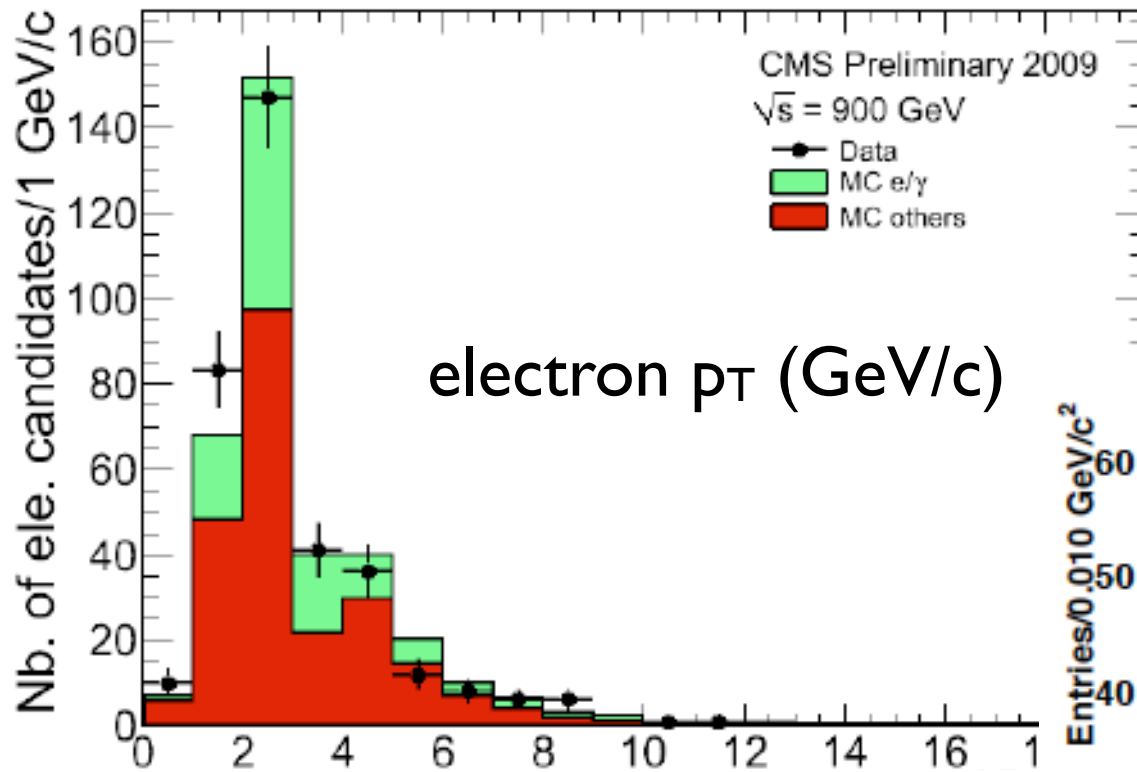


$\eta$   
sim



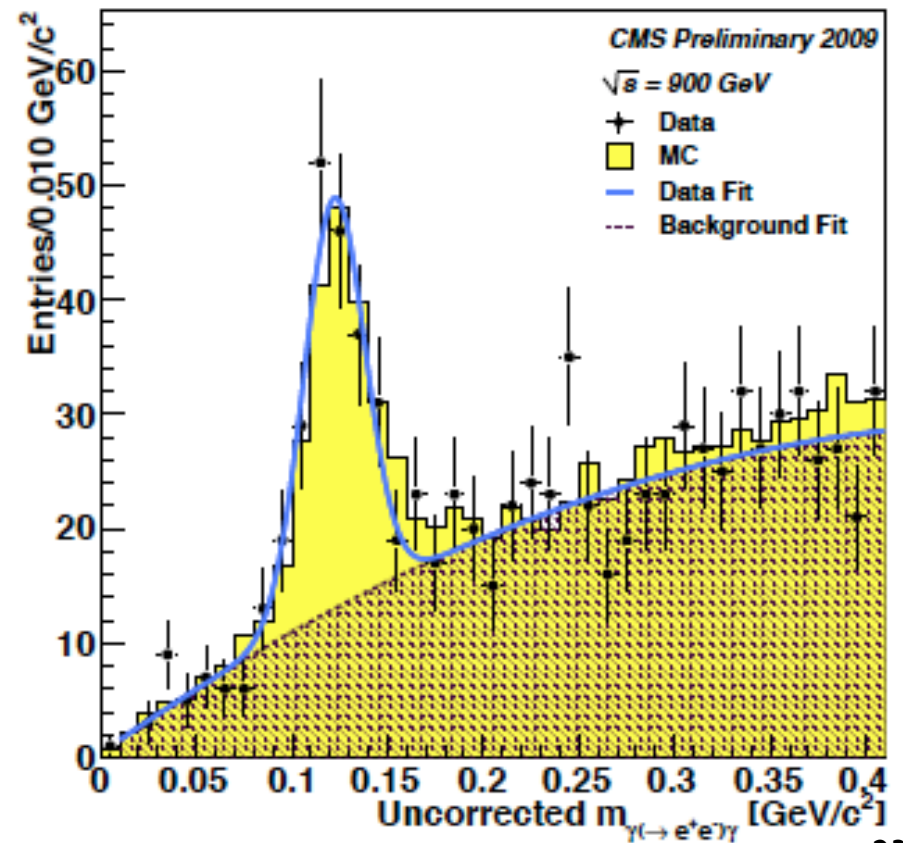
$\pi^0$  and  $\eta$  useful for inter-crystal calibration

# Electrons, photons, conversions



electron and photon  
reconstruction doing well

$\pi^0$  from  $\gamma + (\gamma \rightarrow ee)$



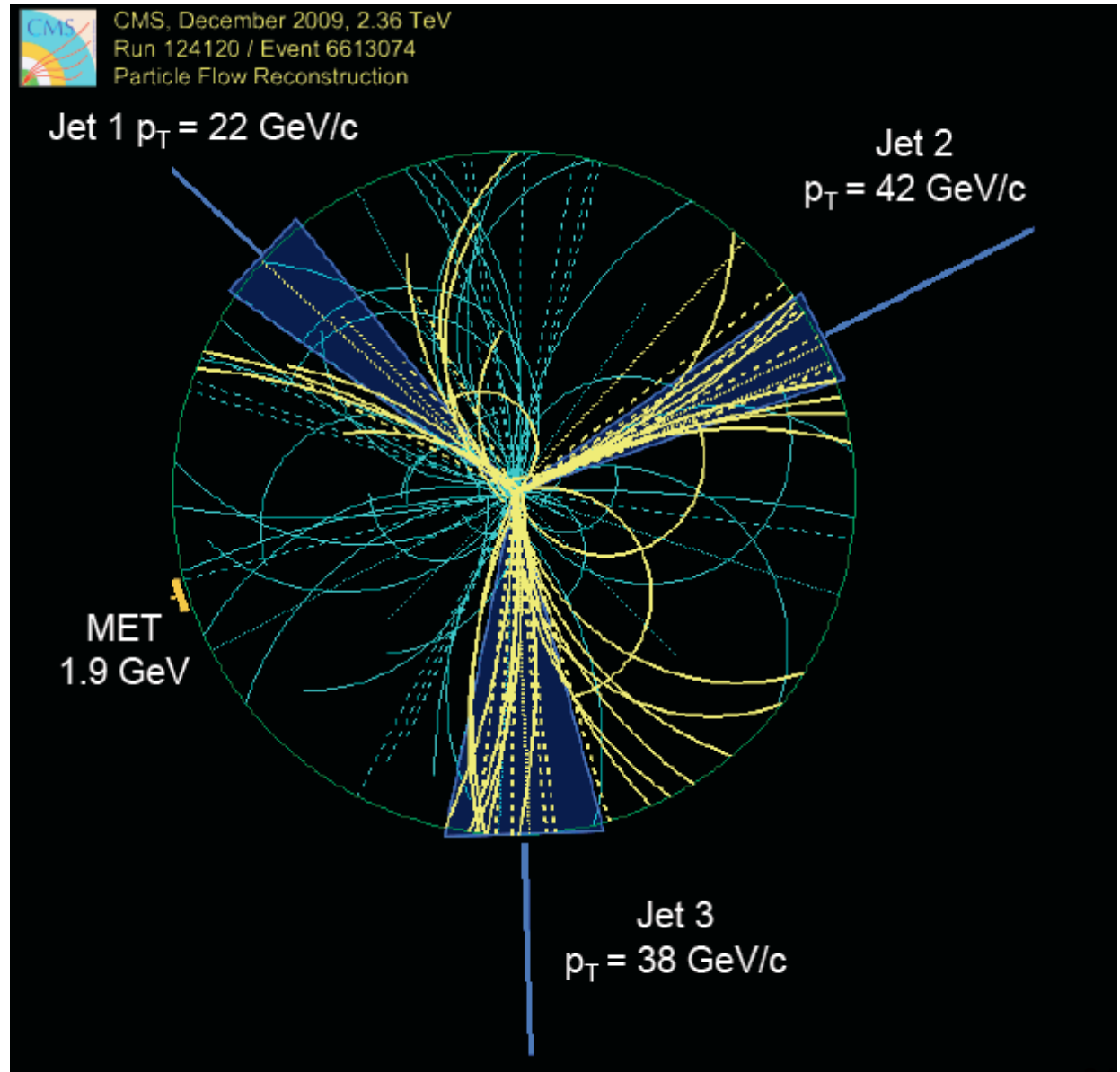
# Jets, Jets and more Jets!

1. Calorimeter jets (CALO)

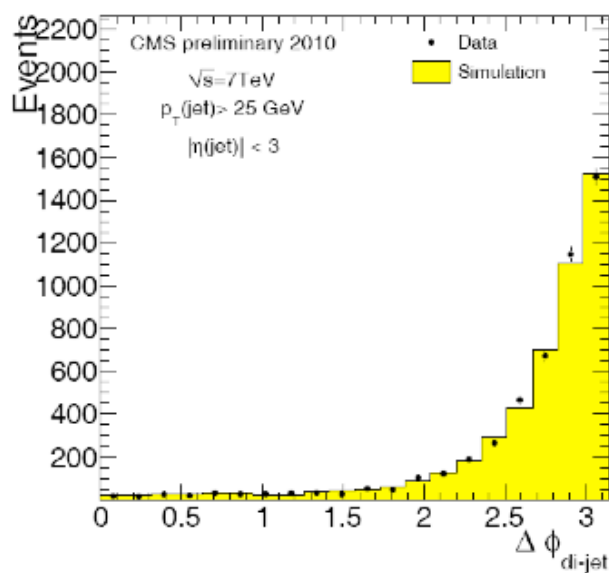
2. “Jet Plus Tracks” jets (JPT)

3. Particle flow jets

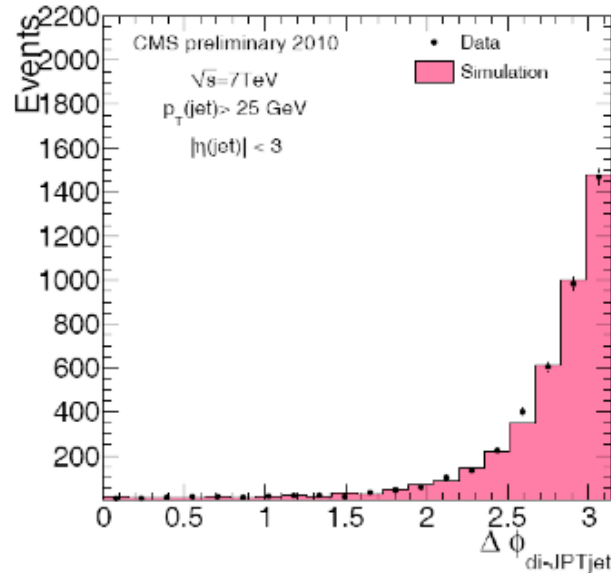
jet algorithm:  
anti- $k_T$ ,  $R = 0.5$



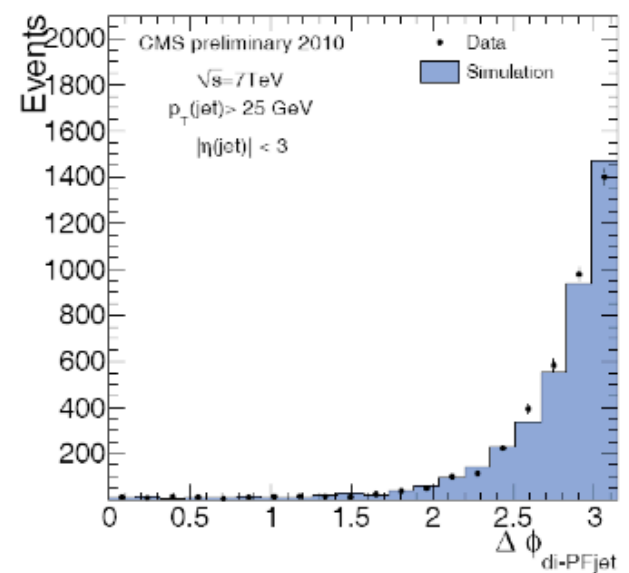
# Jets with the first nb<sup>-1</sup> at 7 TeV



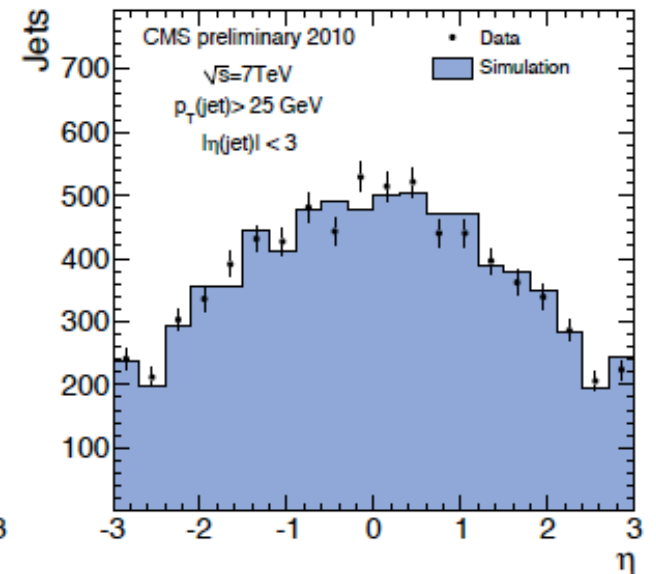
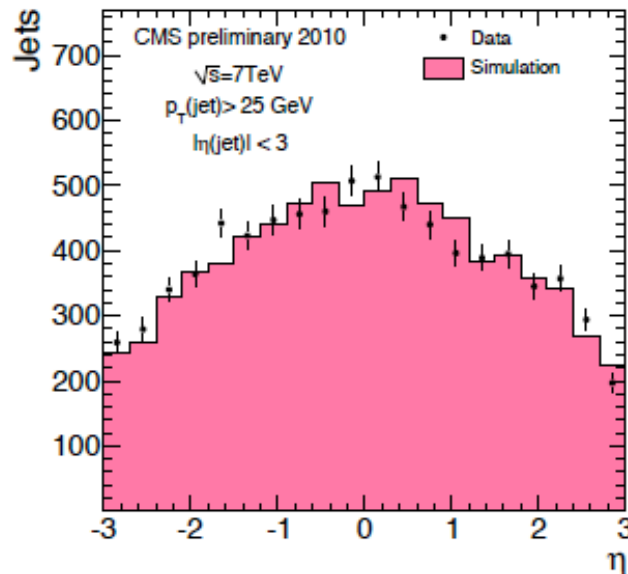
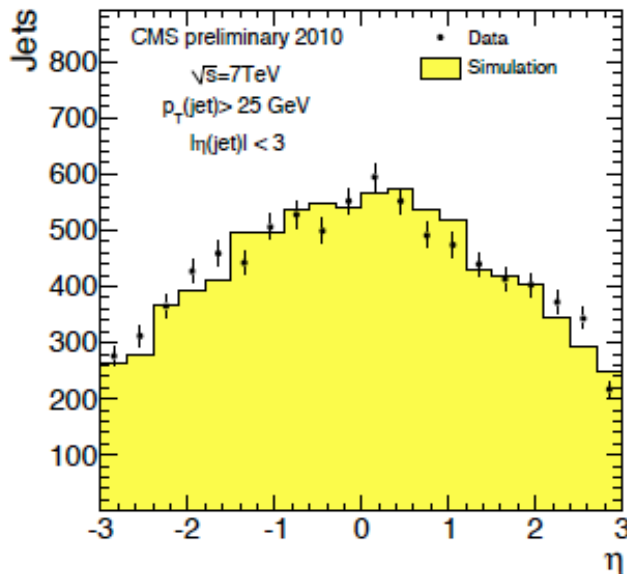
calorimeter



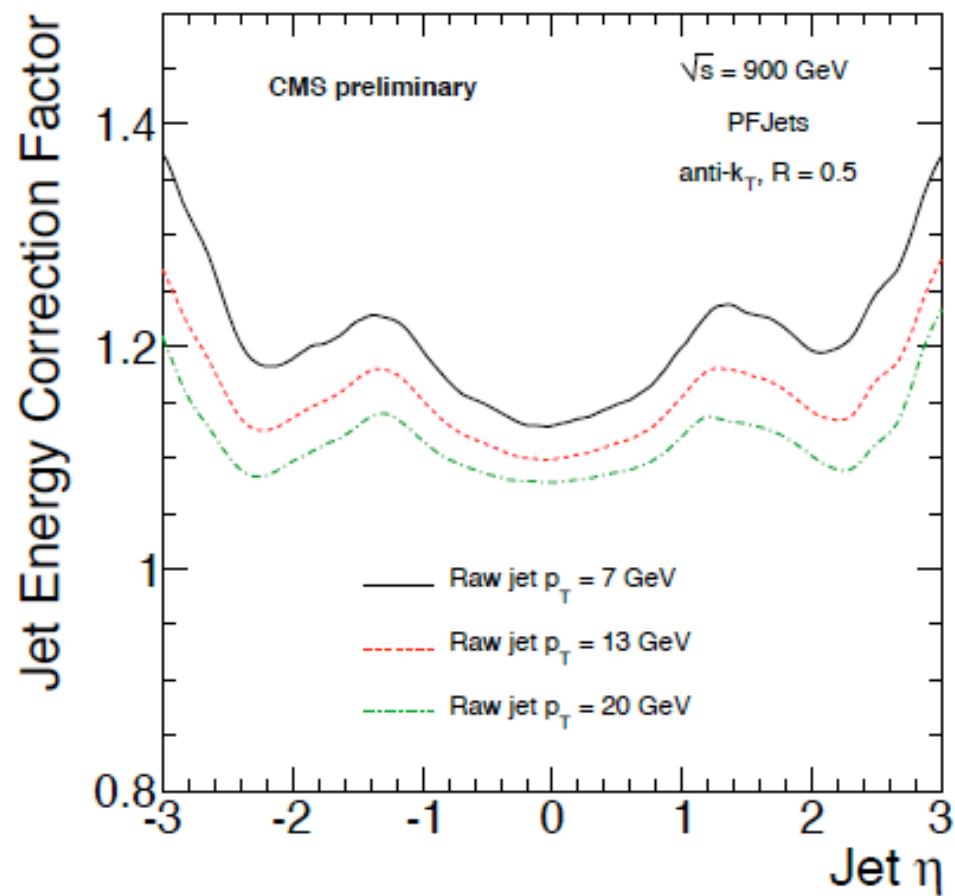
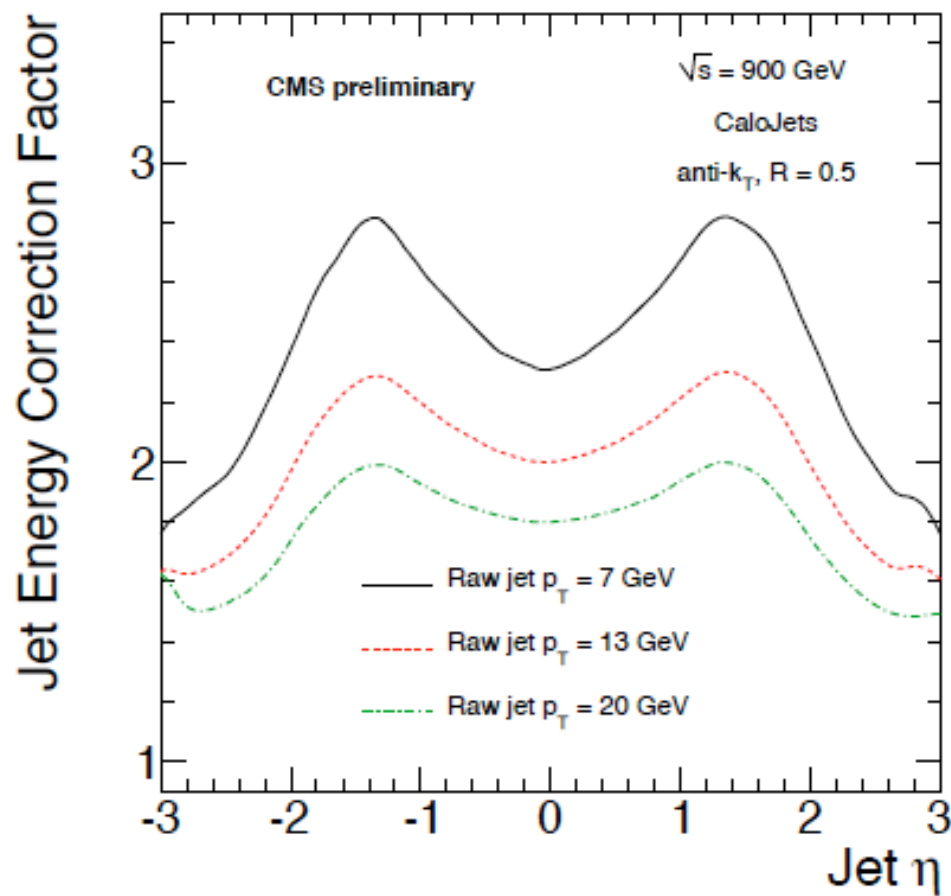
jet plus track



particle flow



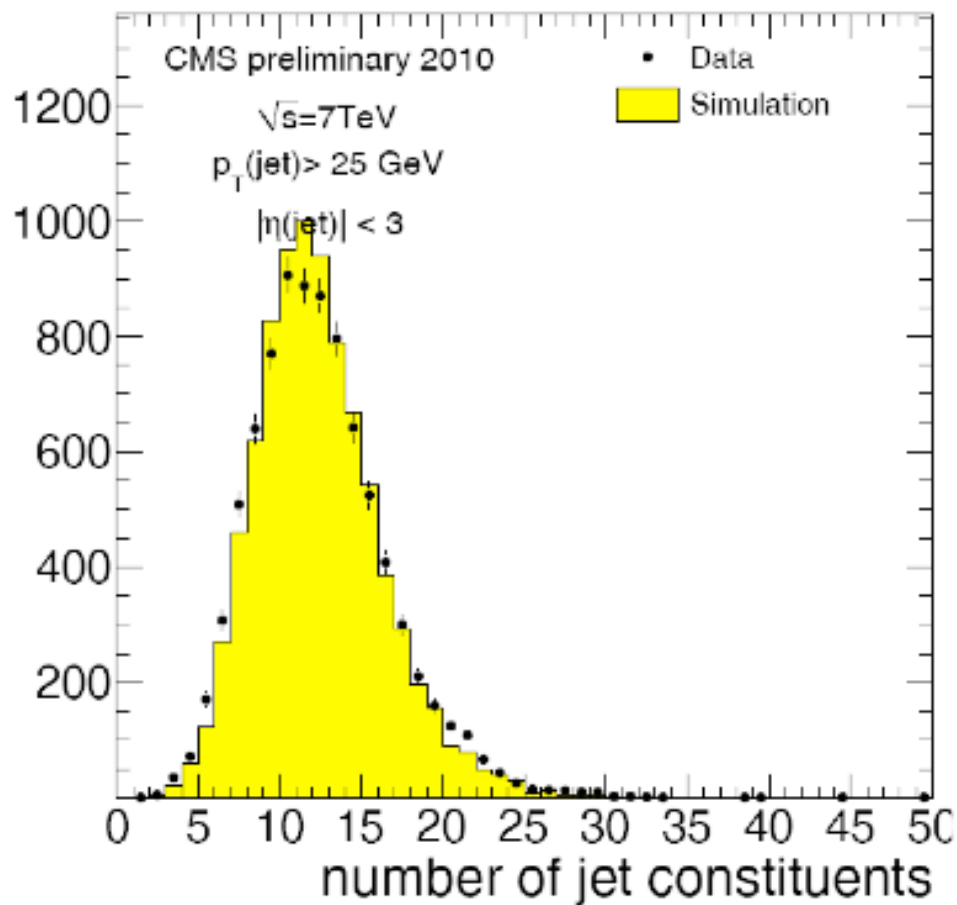
# Jet Corrections



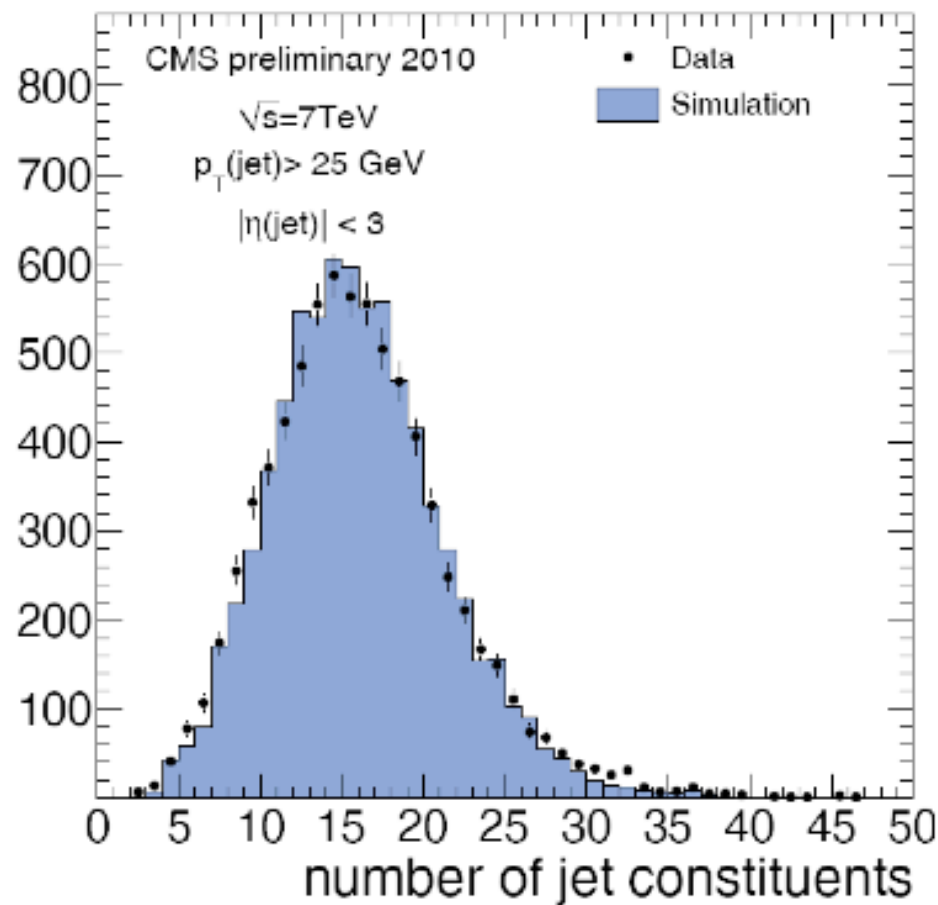
Particle flow reduces magnitude of jet corrections

# Particle flow jet performance

calorimeter



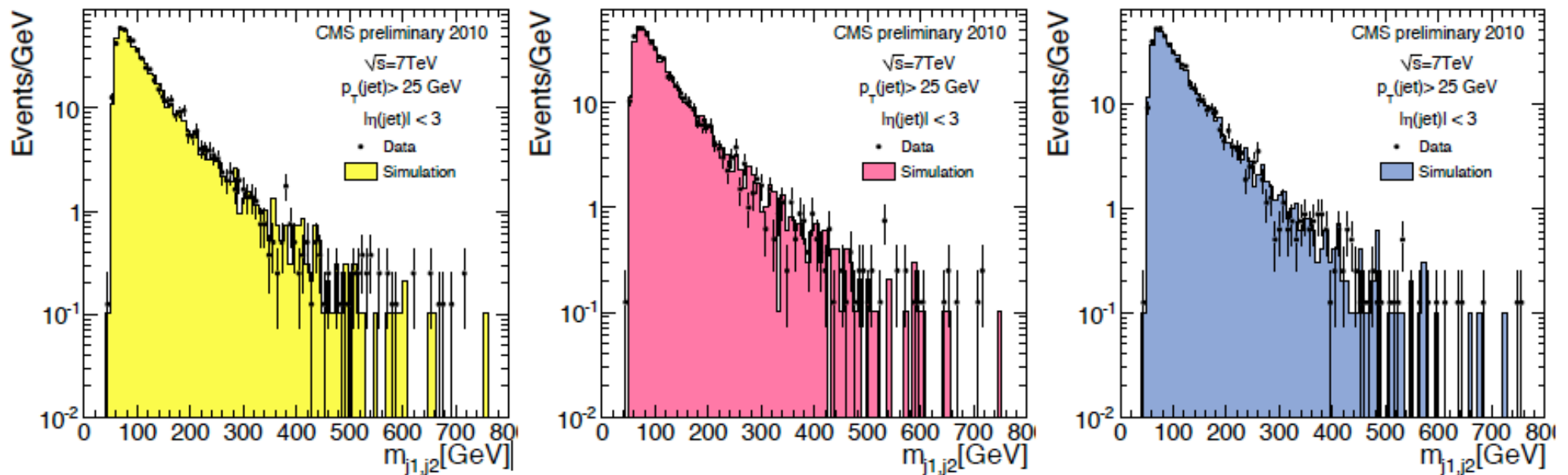
particle flow





# Di-Jets in first $\text{nb}^{-1}$ at 7 TeV

Creeping up to Tevatron turf...



...will soon surpass it!

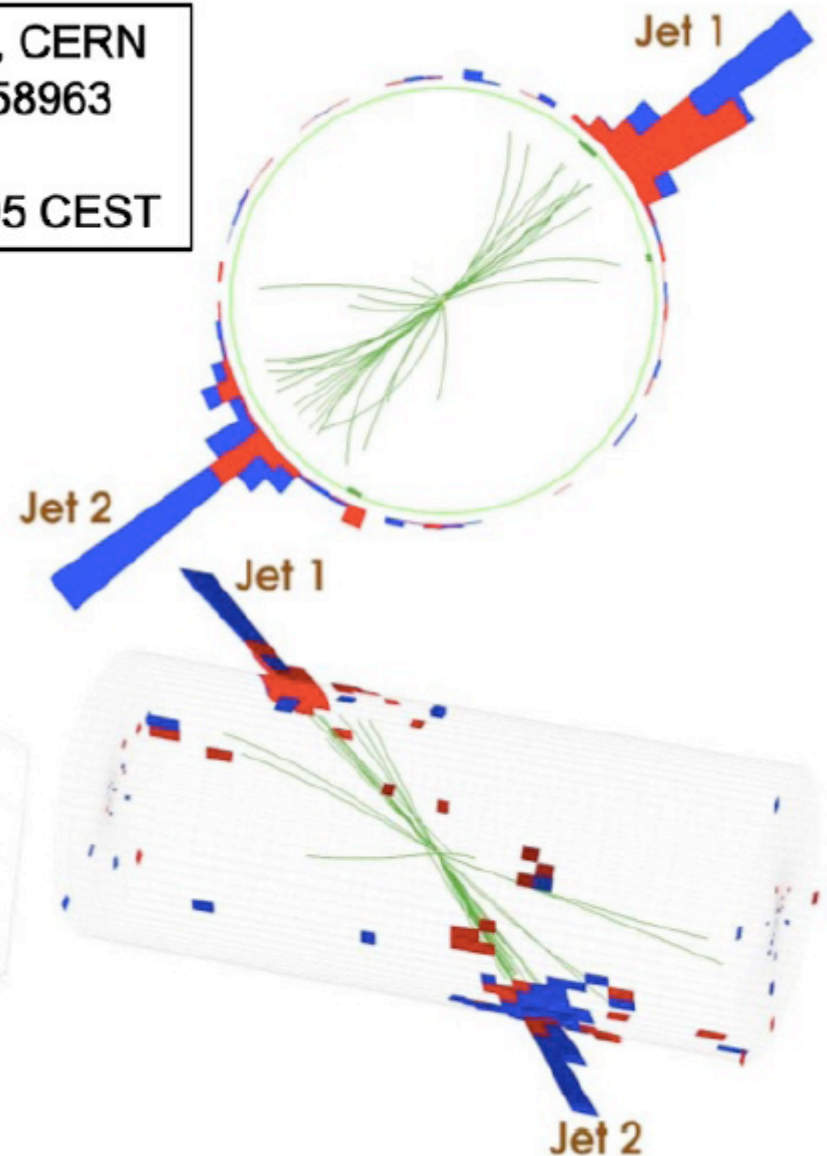
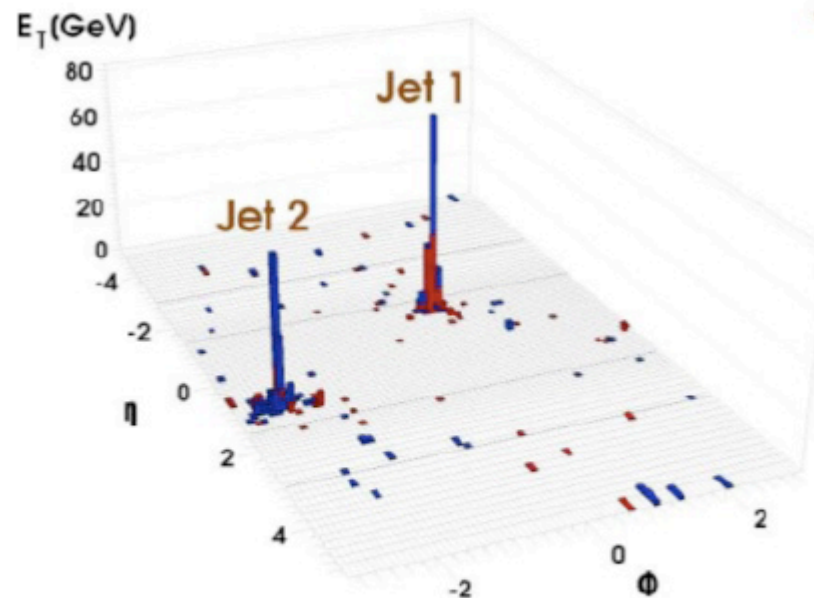


# High-mass Di-Jet event at 7 TeV

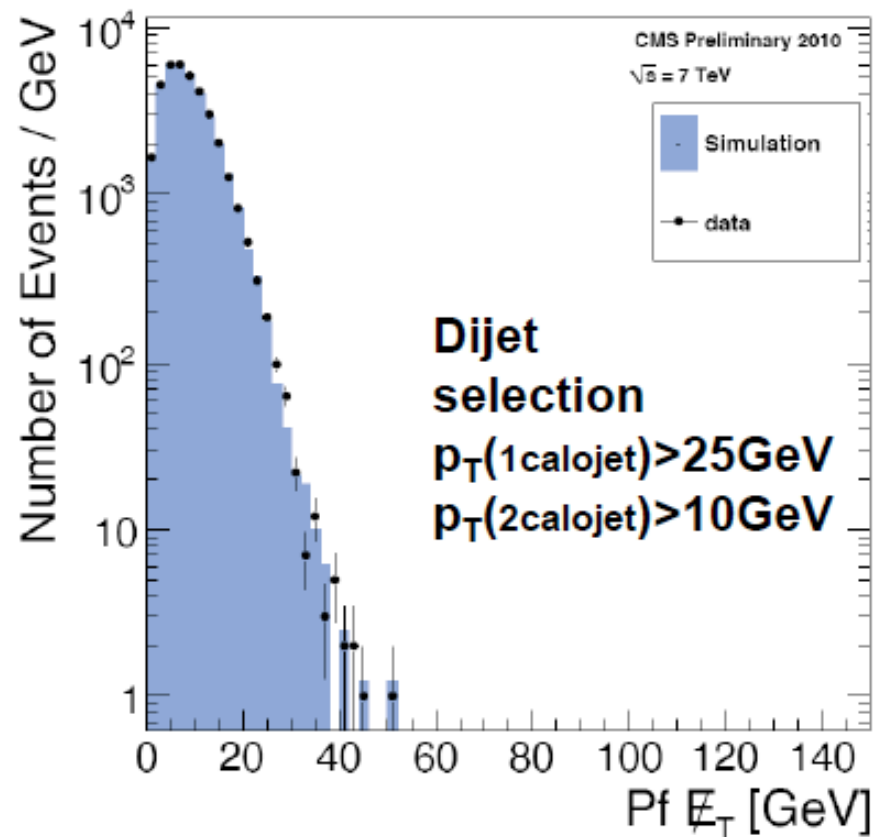
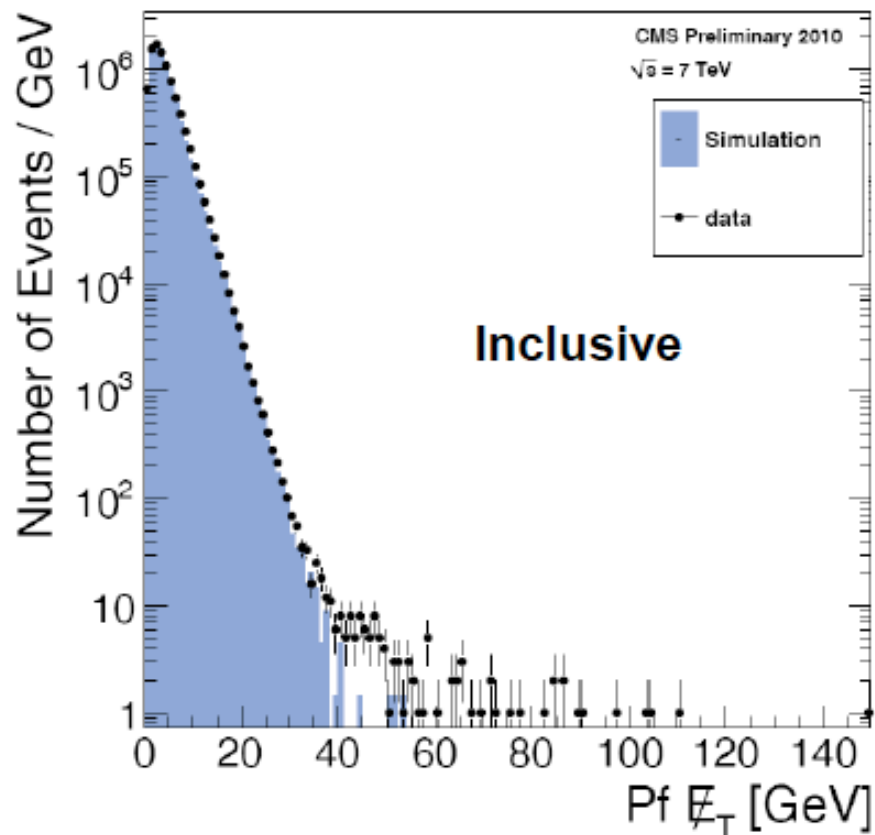


CMS Experiment at LHC, CERN  
Run 133450 Event 16358963  
Lumi section: 285  
Sat Apr 17 2010, 12:25:05 CEST

Jet1  $p_T$  : 253 GeV  
Jet2  $p_T$  : 244 GeV  
Dijet Mass : 764 GeV



# Missing Transverse Energy

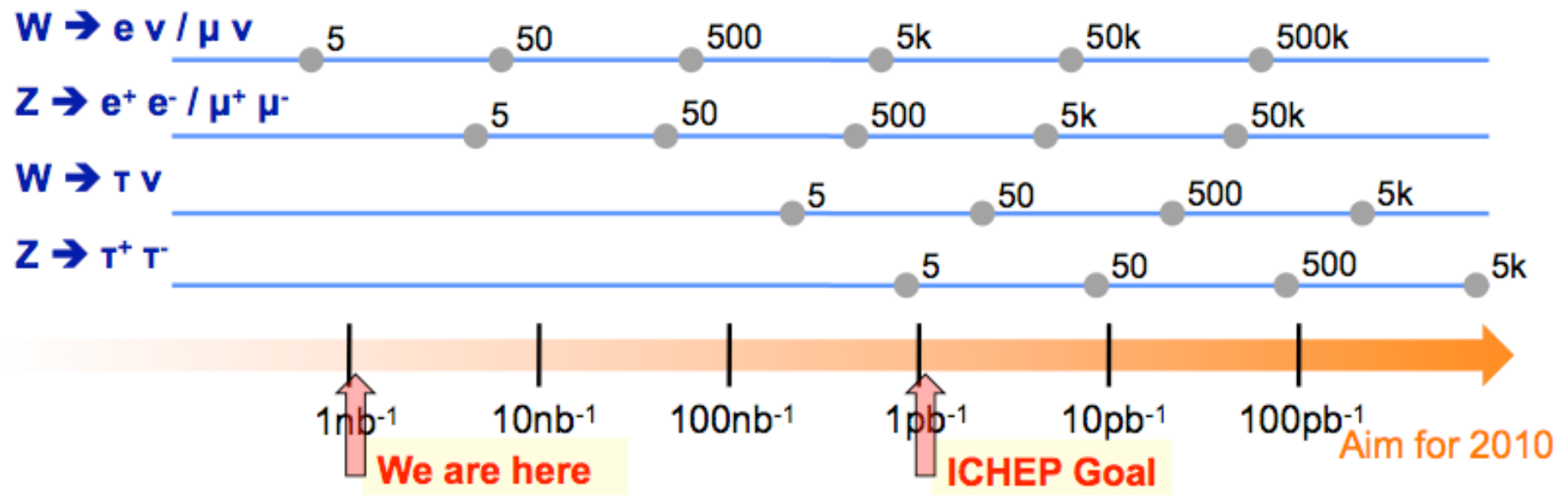


Monte Carlo (minbias) describes the data well over 5 orders of magnitude. High tails subject of ongoing study.

# Early Physics: Ws and Zs

$W^+ : 56 \text{ nb}$      $W^- : 39.5 \text{ nb}$     total: 95.5 nb

$Z/\gamma^* : 49.5 \text{ nb}$



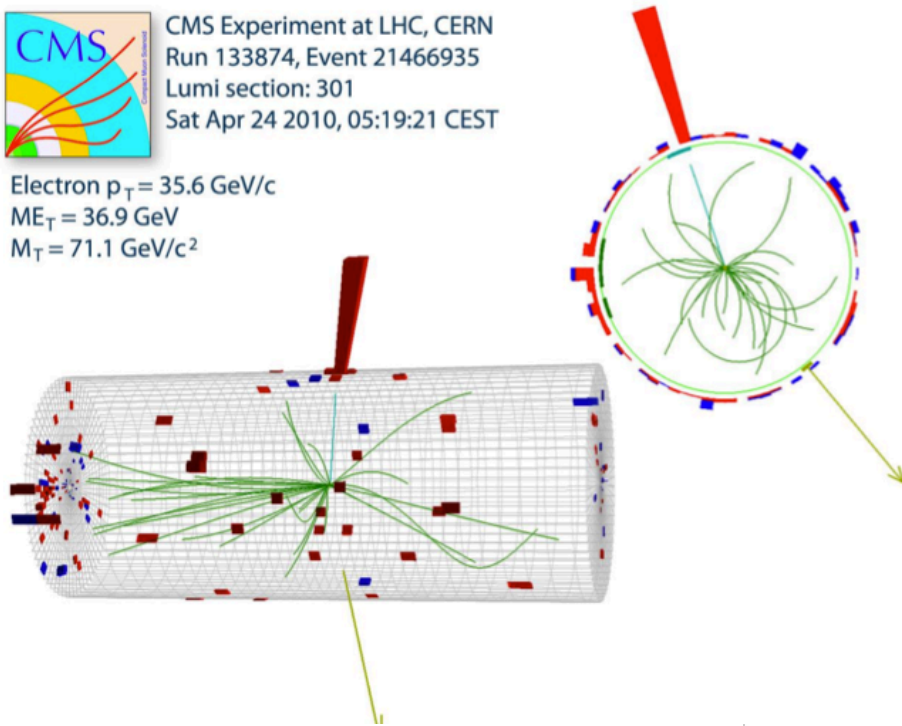
# Expected/Observed, 1 nb<sup>-1</sup>

For 1 nb<sup>-1</sup> at 7 TeV, after acceptance, expect  
8 W candidates and 0.8 Z candidates.



CMS Experiment at LHC, CERN  
Run 133874, Event 21466935  
Lumi section: 301  
Sat Apr 24 2010, 05:19:21 CEST

Electron  $p_T = 35.6$  GeV/c  
 $ME_T = 36.9$  GeV  
 $M_T = 71.1$  GeV/c<sup>2</sup>



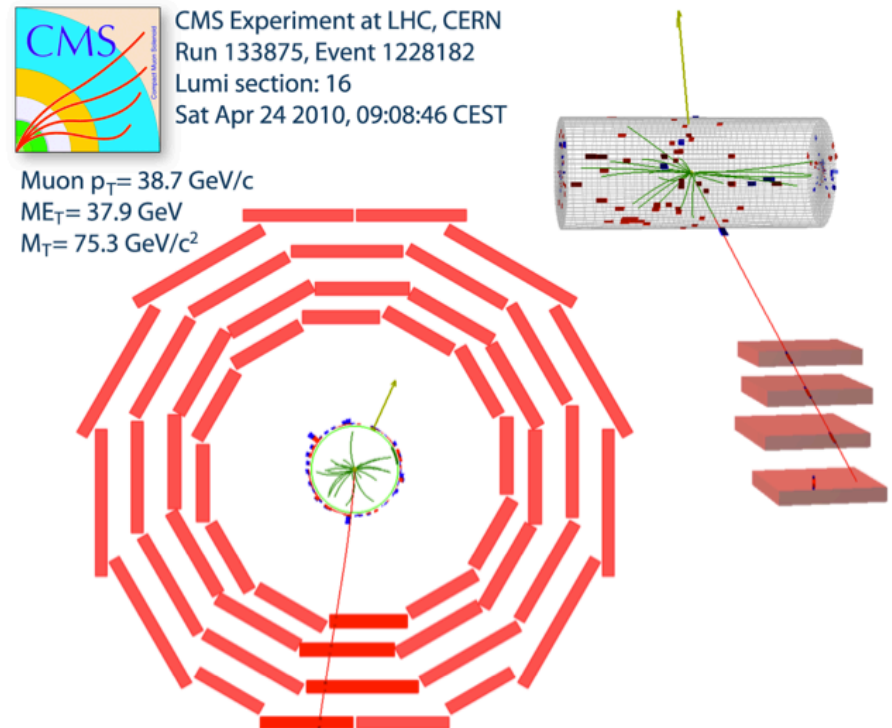
$W \rightarrow e\nu$ :

3 candidates found



CMS Experiment at LHC, CERN  
Run 133875, Event 1228182  
Lumi section: 16  
Sat Apr 24 2010, 09:08:46 CEST

Muon  $p_T = 38.7$  GeV/c  
 $ME_T = 37.9$  GeV  
 $M_T = 75.3$  GeV/c<sup>2</sup>



$W \rightarrow \mu\nu$ :

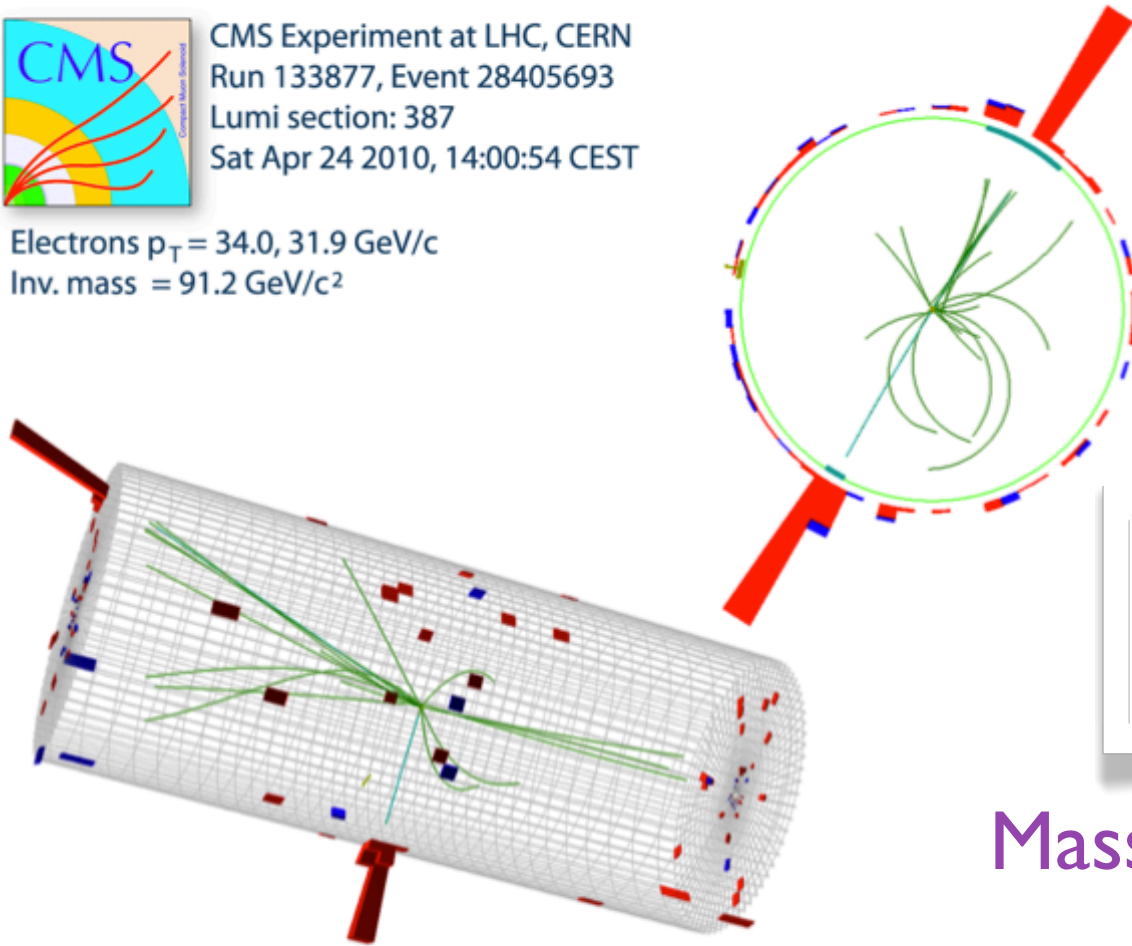
3 candidates found

# Expected/Observed, 1 nb<sup>-1</sup>



CMS Experiment at LHC, CERN  
Run 133877, Event 28405693  
Lumi section: 387  
Sat Apr 24 2010, 14:00:54 CEST

Electrons  $p_T = 34.0, 31.9$  GeV/c  
Inv. mass = 91.2 GeV/c<sup>2</sup>



$Z \rightarrow ee$ :  
one candidate found

$\text{Mass}(ee) = 91.2 \text{ GeV}/c^2$

Now we have  $>15 \text{ nb}^{-1}$  so things are moving...

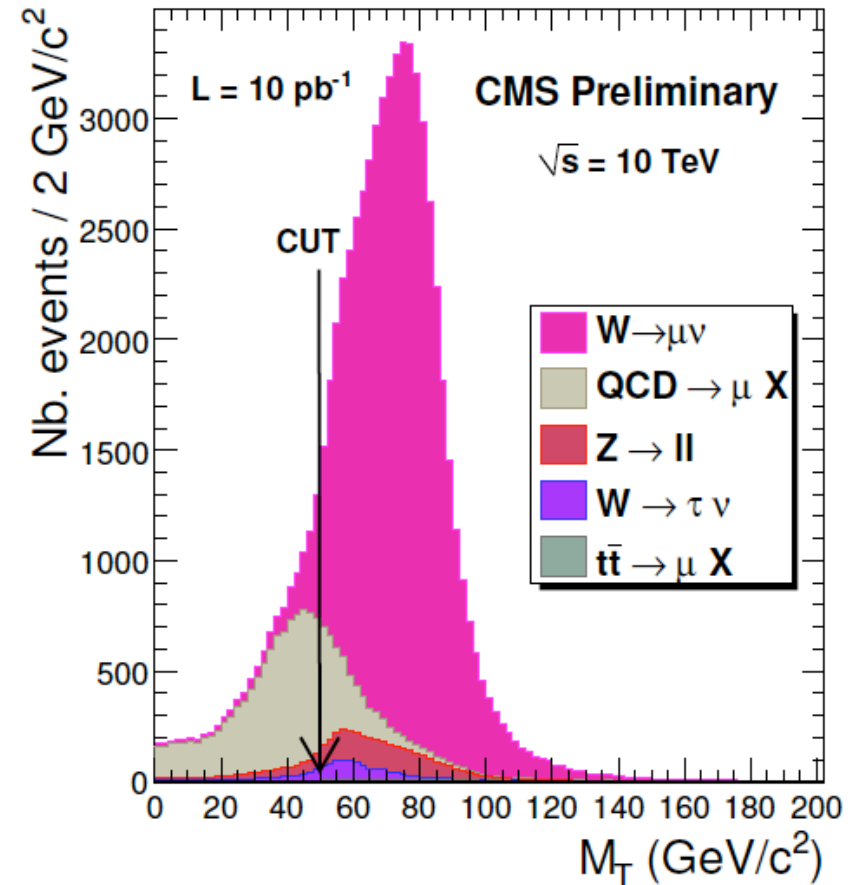
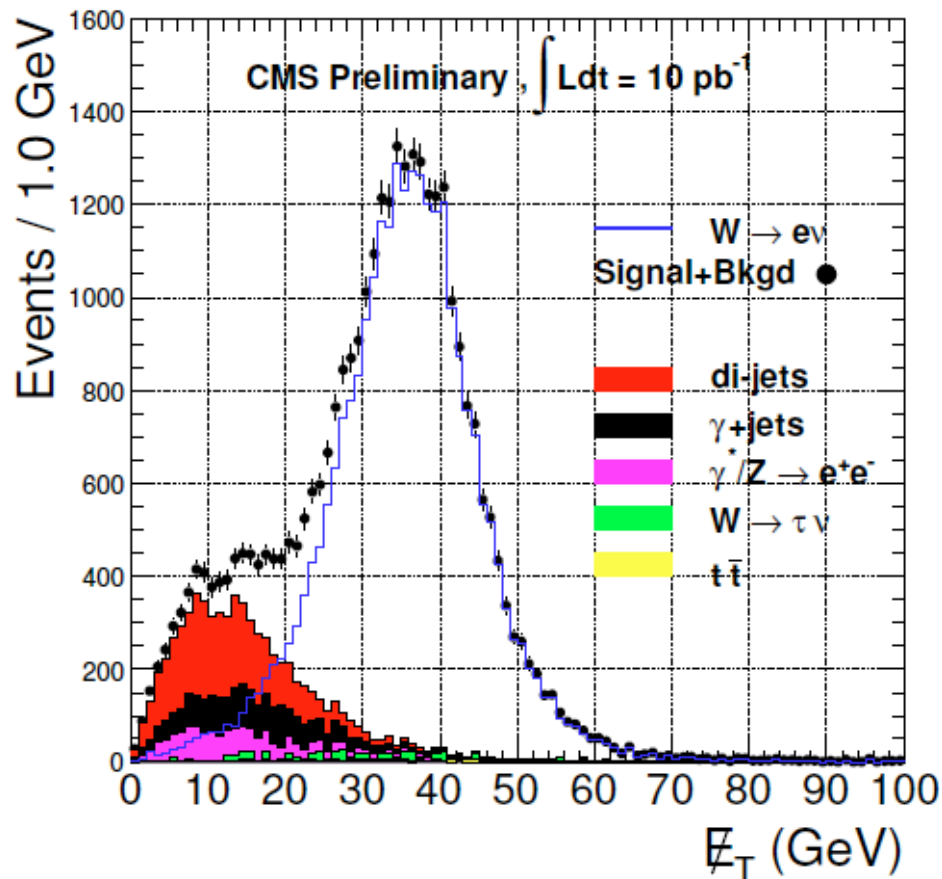
# Early Physics: $W \rightarrow \ell \nu$

## Pseudo-data

electrons

10 TeV

muons



Expect very clean  $W \rightarrow \ell \nu$  distributions



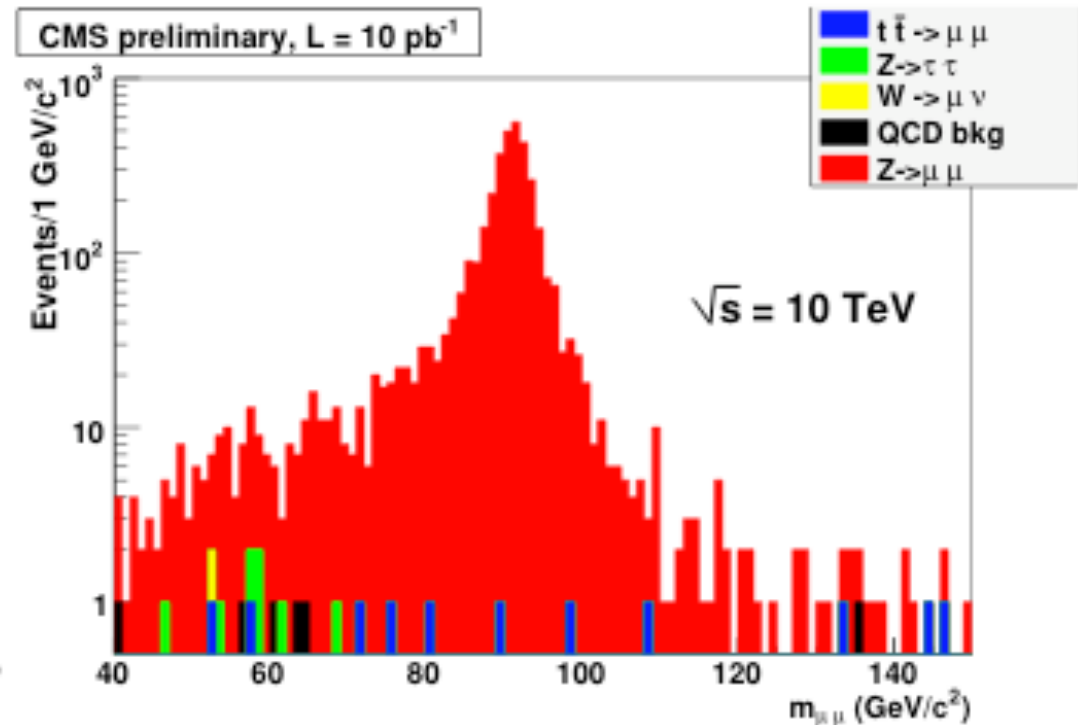
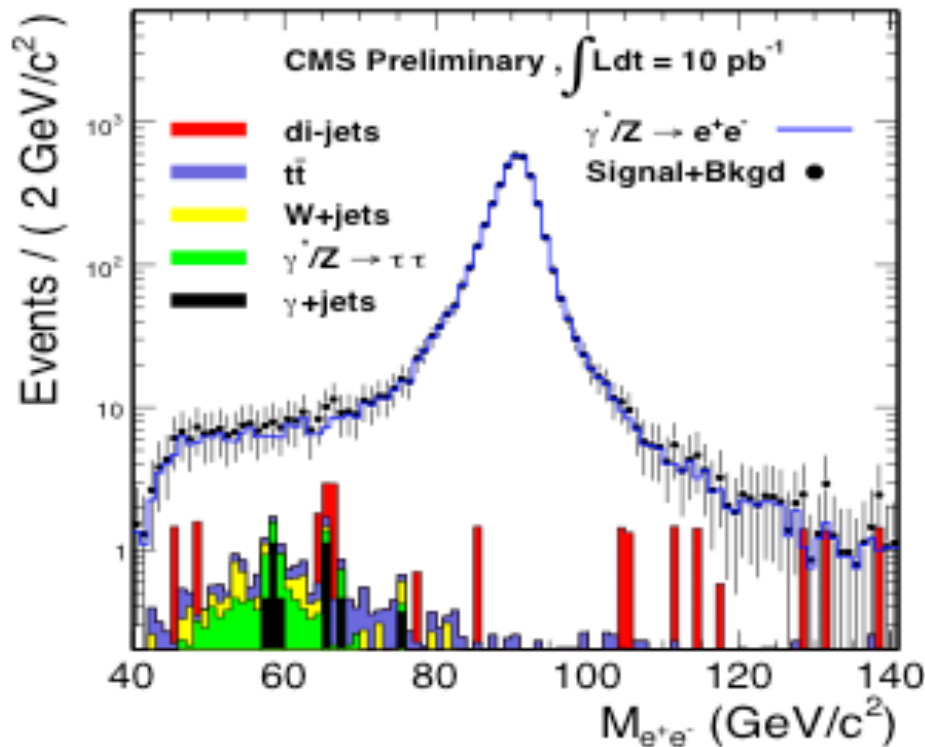
# Early Physics: $Z \rightarrow \ell\ell$

Pseudo-data

10 TeV

electrons

muons

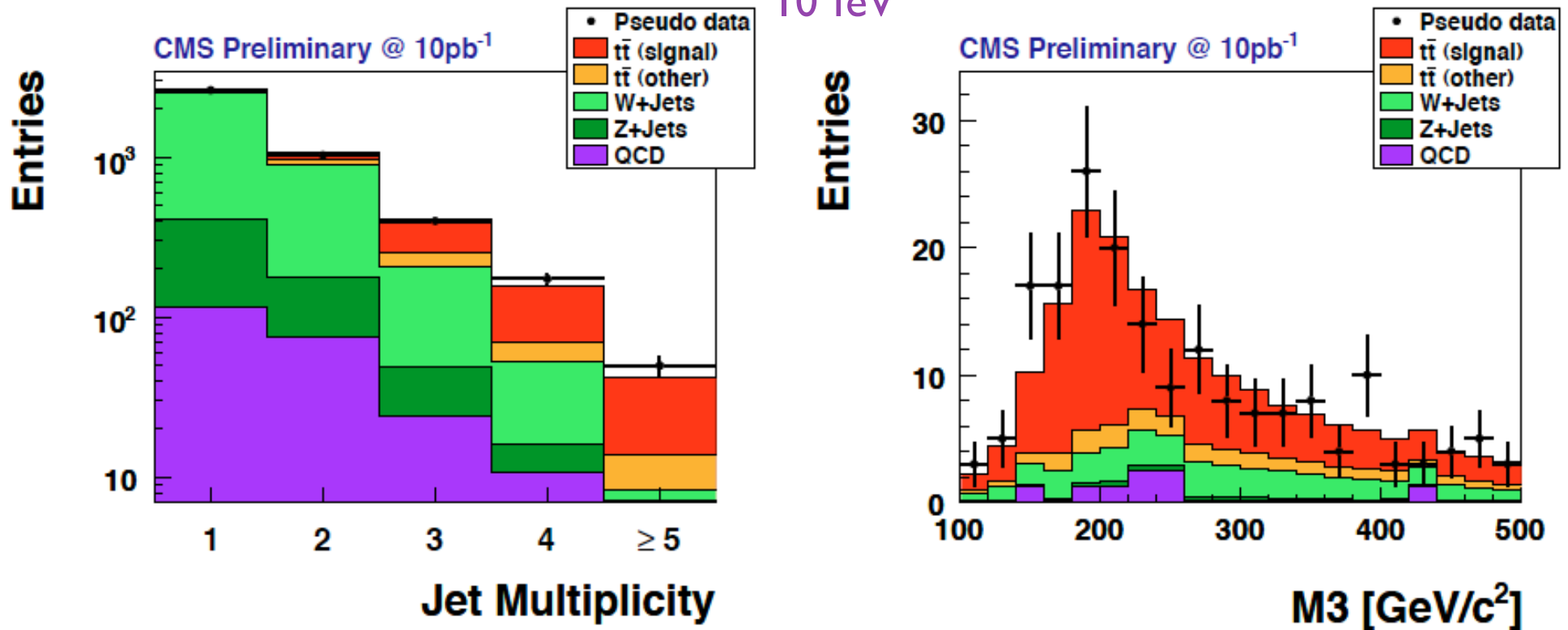


$Z \rightarrow \ell\ell$  is our most important early calibration.  
Significant samples expected very soon!

# Early Physics: Top quarks

## Pseudo-data

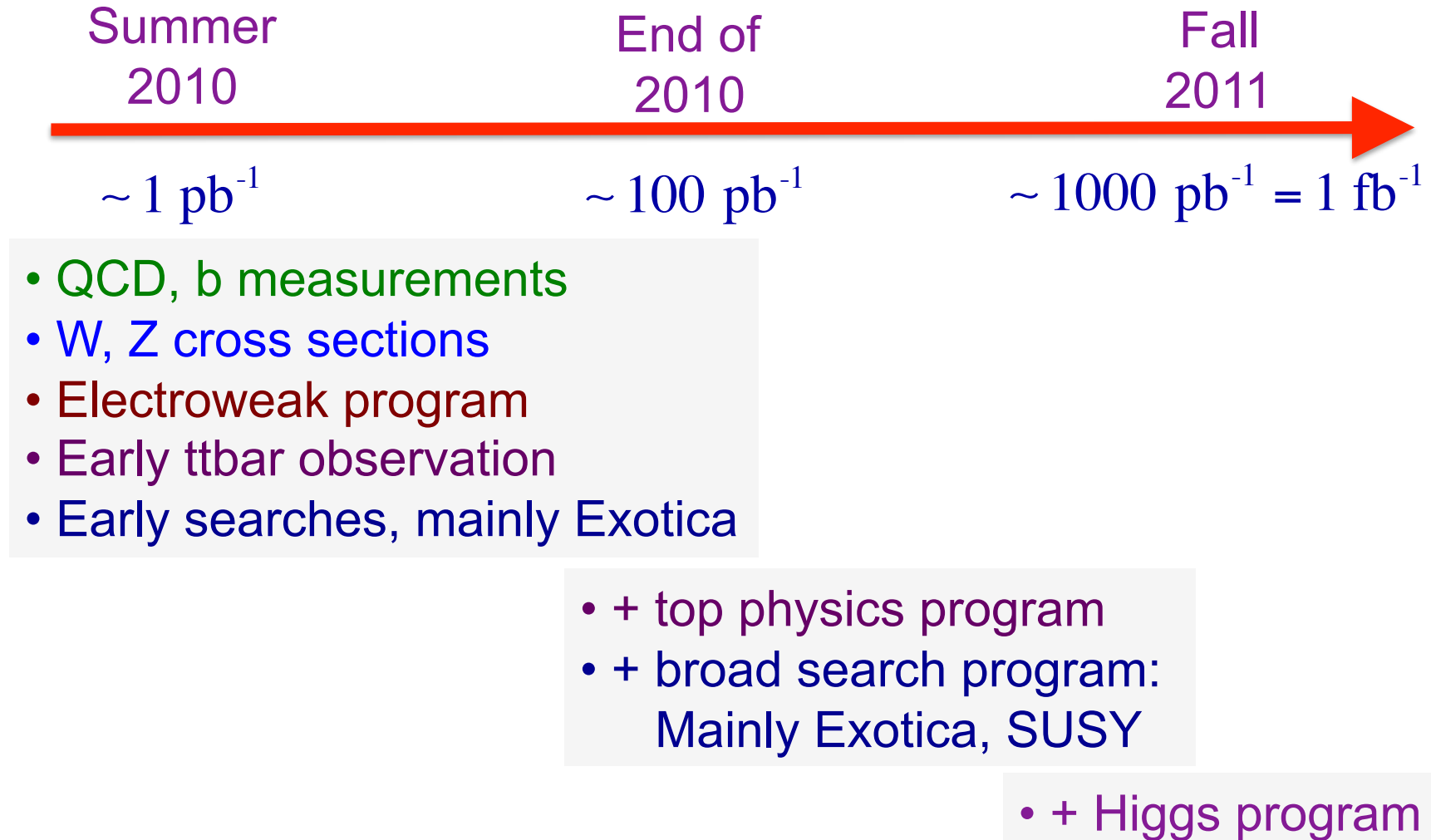
10 TeV



With  $\sim 20 \text{ pb}^{-1}$  at 7 TeV expect to find hundreds of  $t\bar{t}$  events. Can use to help calibrate jet energy scale, b-tagging, MET, and later test boosted top algorithms.

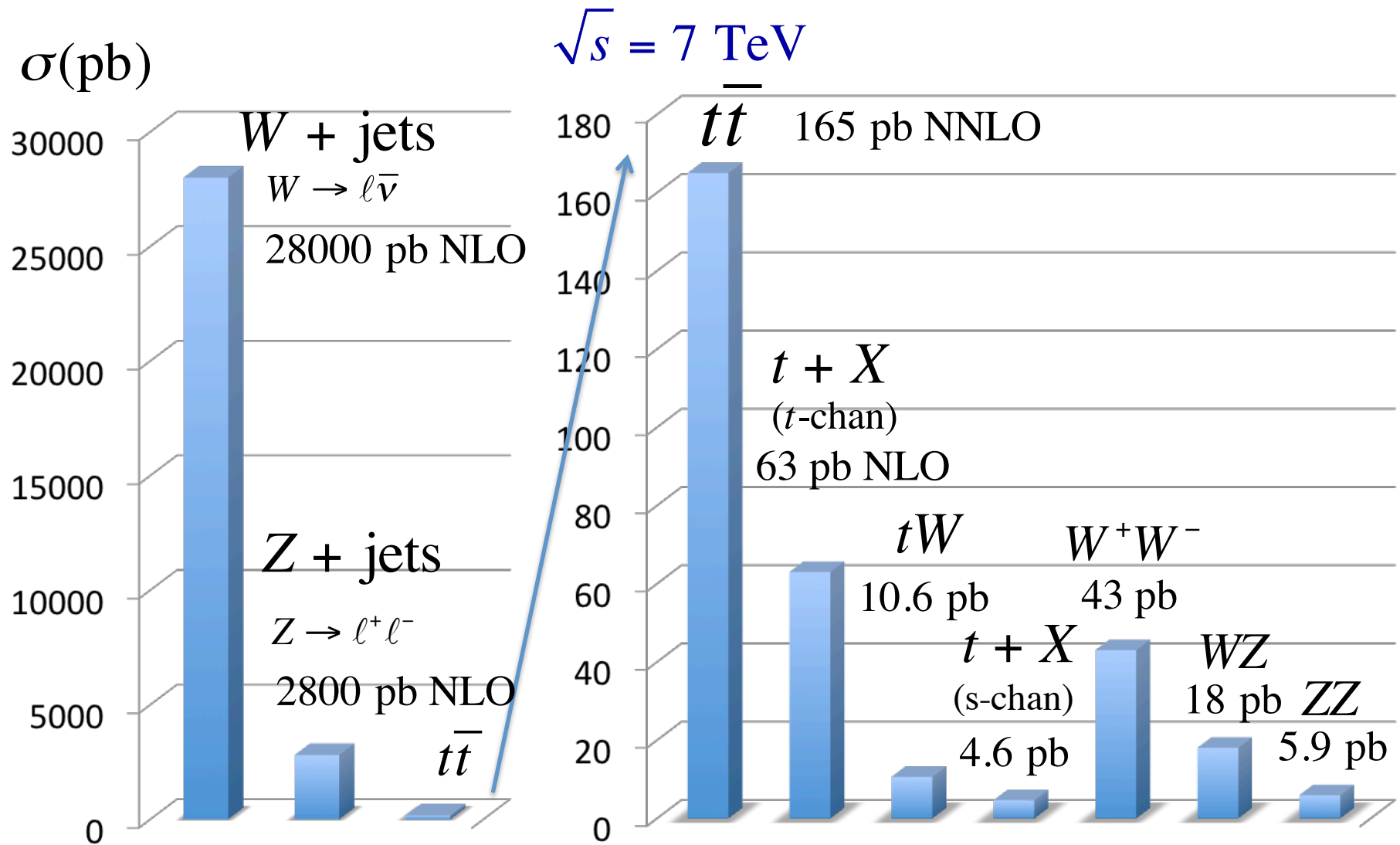


# Progression of 7 TeV Run



Early SM studies are critical for laying the foundation for searches.

# Cross Sections for SM Processes



# Recent 7 TeV BSM projections

Available on CMS information server

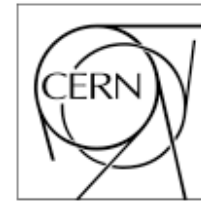
**CMS NOTE 2010/008**



**The Compact Muon Solenoid Experiment**

# **CMS Note**

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland



**5th May 2010**

## **The CMS physics reach for searches at 7 TeV**

The CMS Collaboration

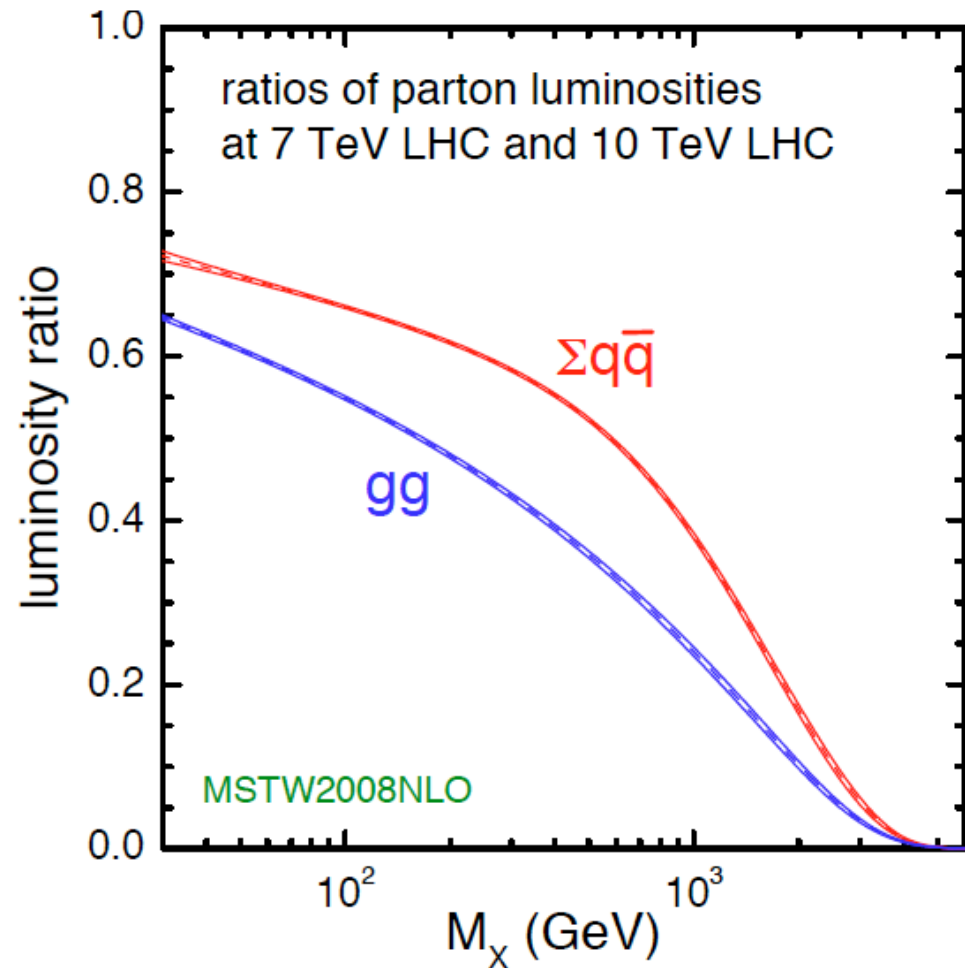
### **Abstract**

Some examples of the expected reach of CMS in terms of searches for new physics, for a proton-proton centre-of-mass energy of 7 TeV, are shown. Integrated luminosities between  $100 \text{ pb}^{-1}$  and  $1 \text{ fb}^{-1}$  are considered. The prospects are preliminary, and based on existing studies at higher energies.

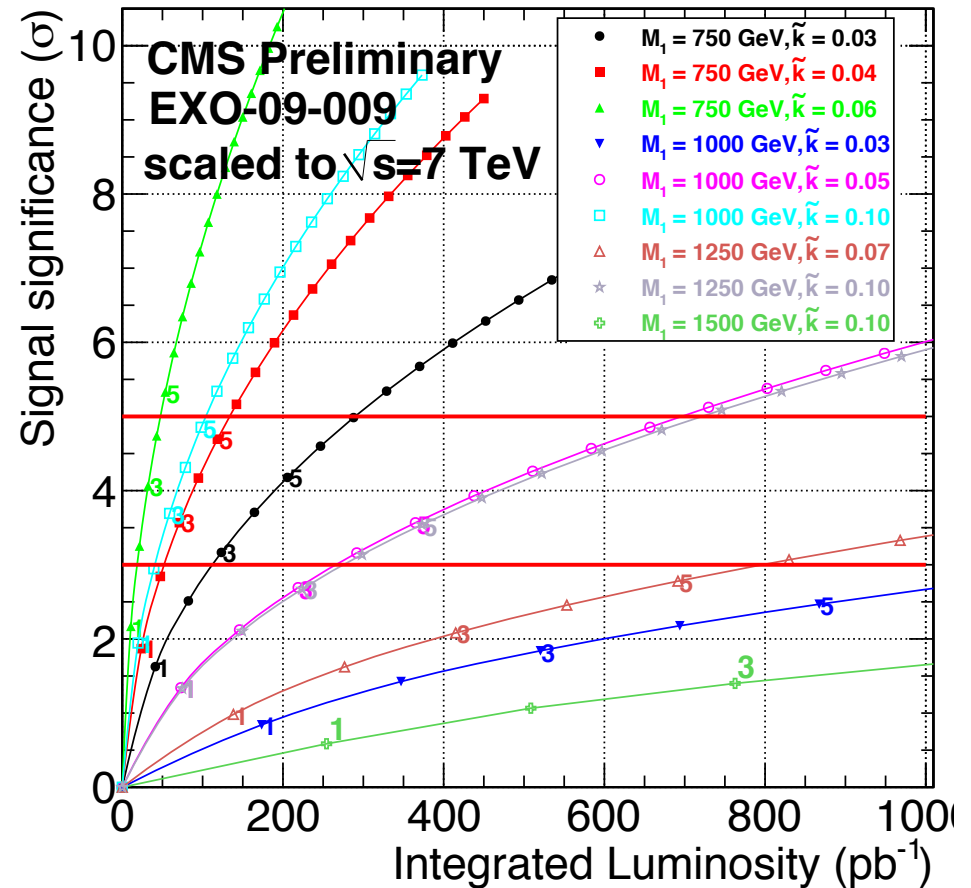
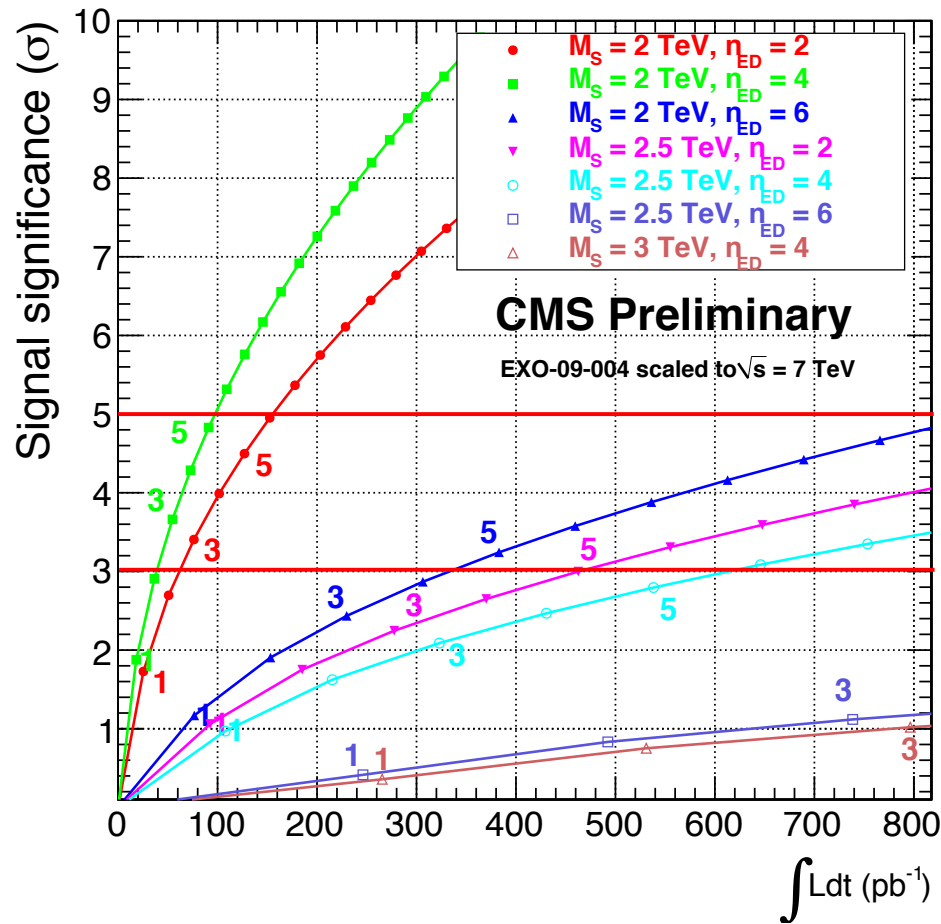
# Rescaling 10 TeV to 7 TeV

Take 10 TeV results for new particle searches and simply scale by expected qq, gg luminosity ratio.

(Ratio courtesy of James Stirling)



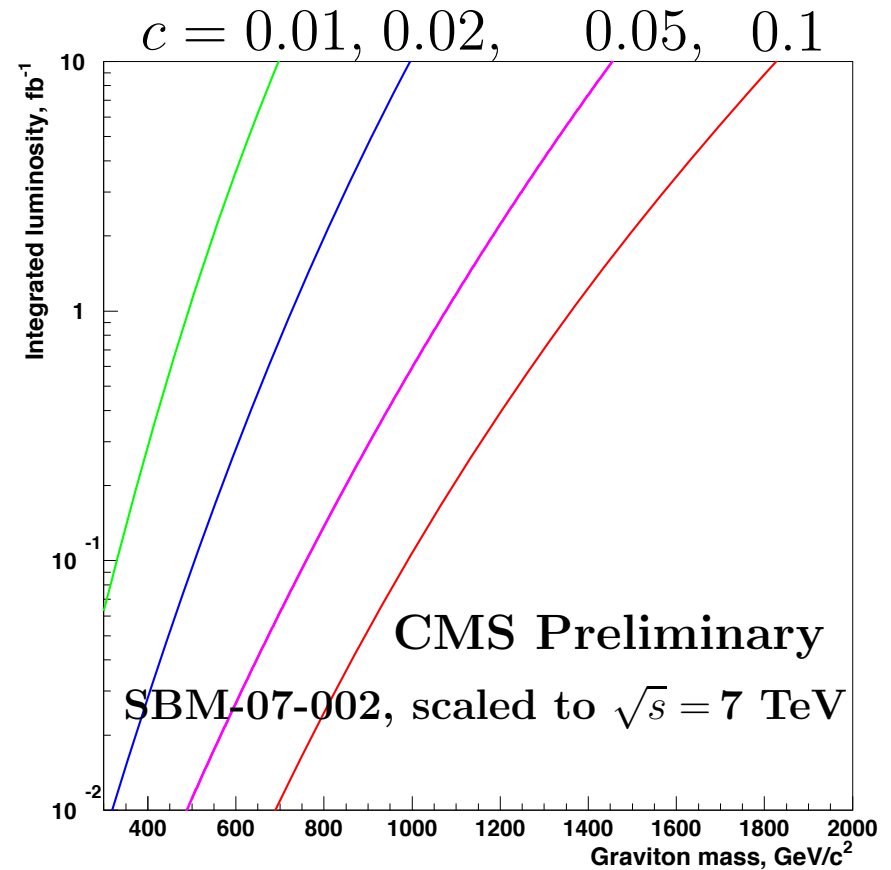
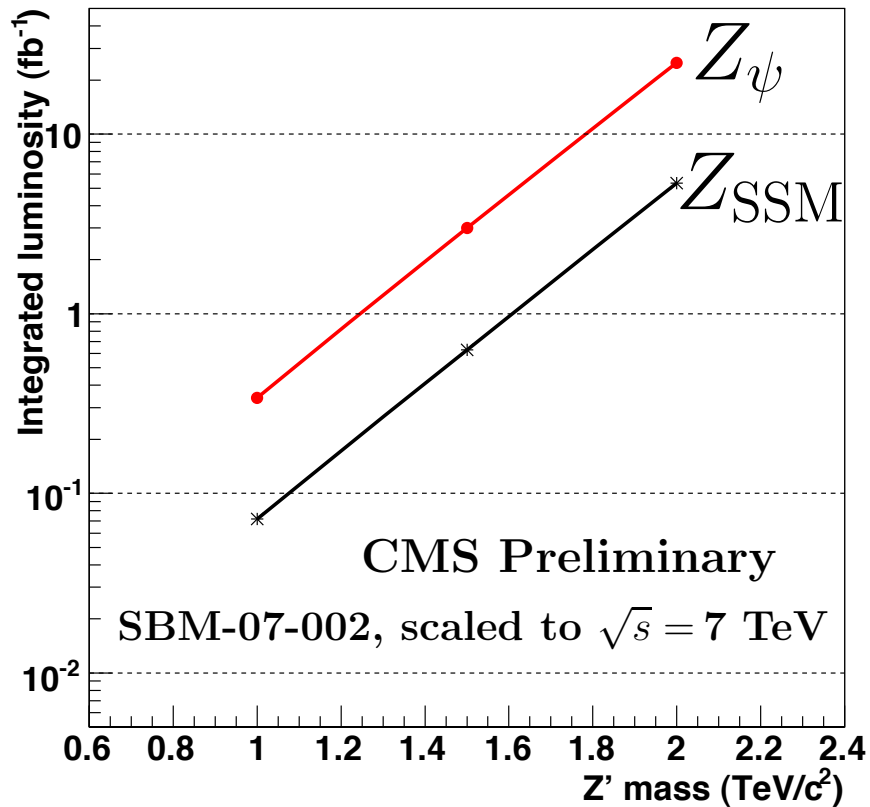
# Early searches: ED in diphotons



Searches for very high mass  $\gamma\gamma$  pairs in large extra dimensions (ED) and Randall-Sundrum models

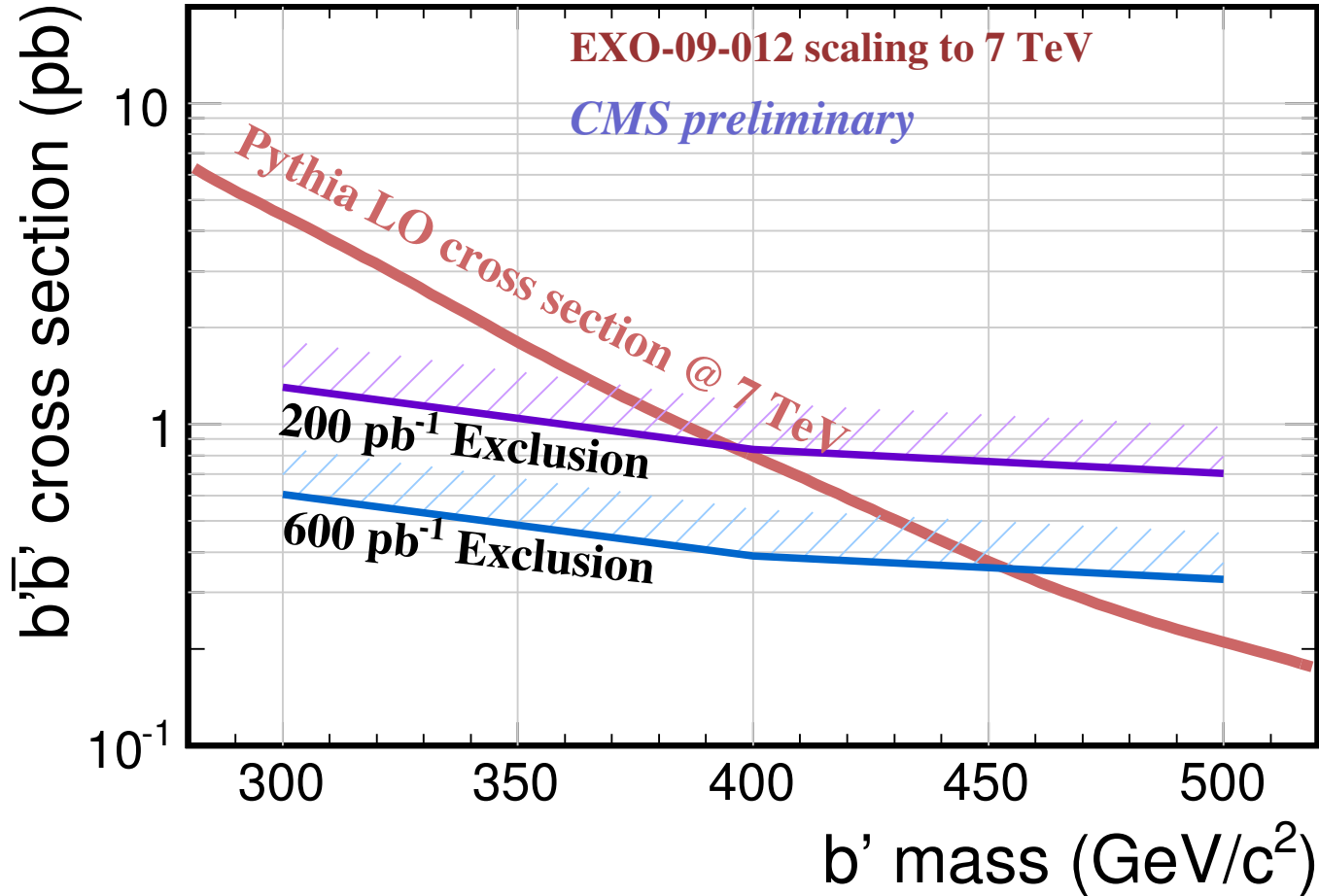


# Early searches: $Z'$ , $ED \rightarrow \mu\mu$



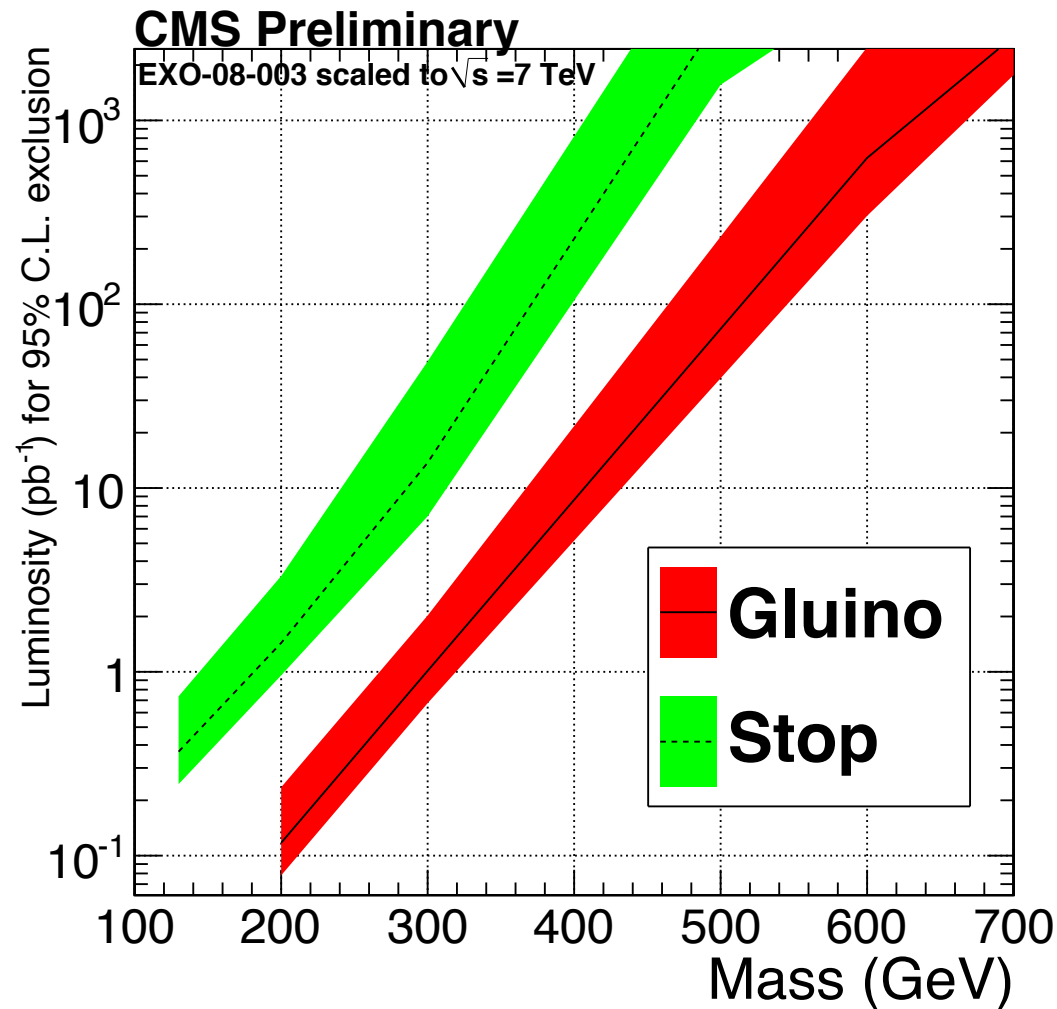
Will beat Tevatron limits with  $1 \text{ fb}^{-1}$ .

# Early searches: $b'$



With  $\sim 200 \text{ pb}^{-1}$  we expect to exceed Tevatron sensitivity

# Early searches: HSCP



Heavy stable charged particles (formerly CHAMPS)

# Early searches: stopped gluinos

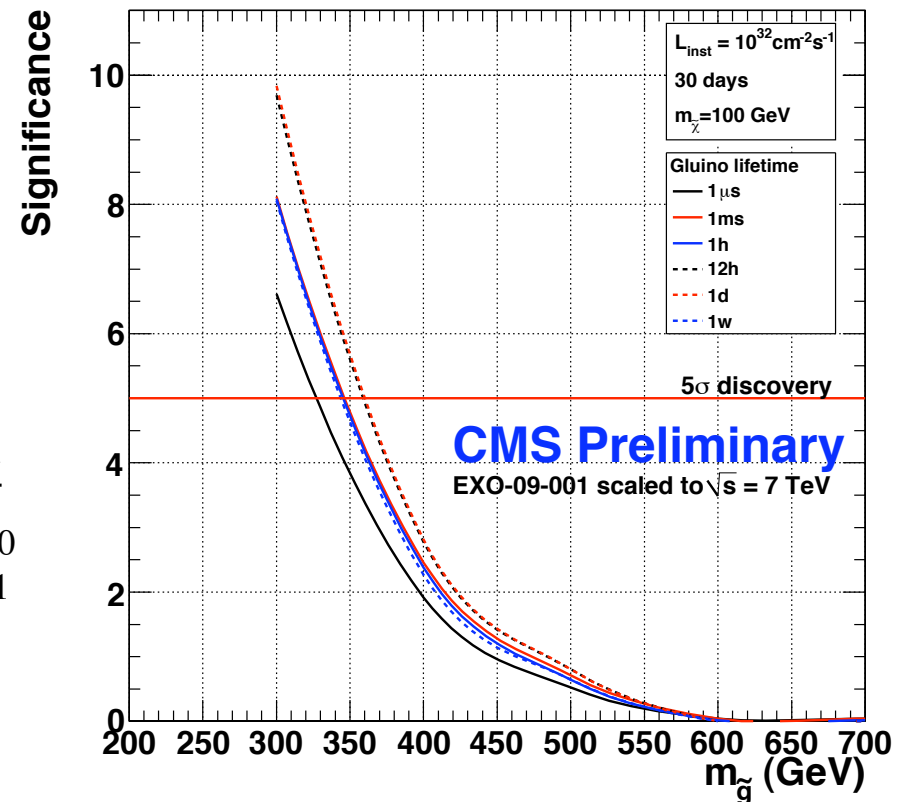
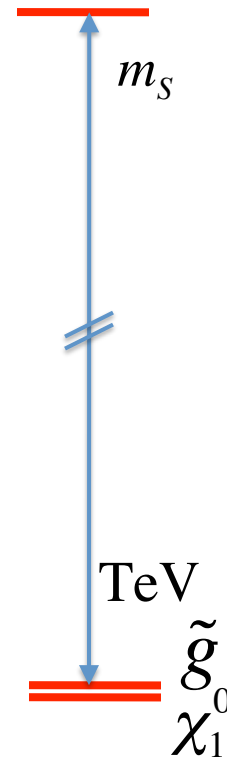
- Split SUSY: Large  $\Delta M$  b/w scalars & gluino

$$\tilde{g} \rightarrow \tilde{q}^* \bar{q}; \quad \tilde{q}^* \rightarrow q \chi_1^0$$

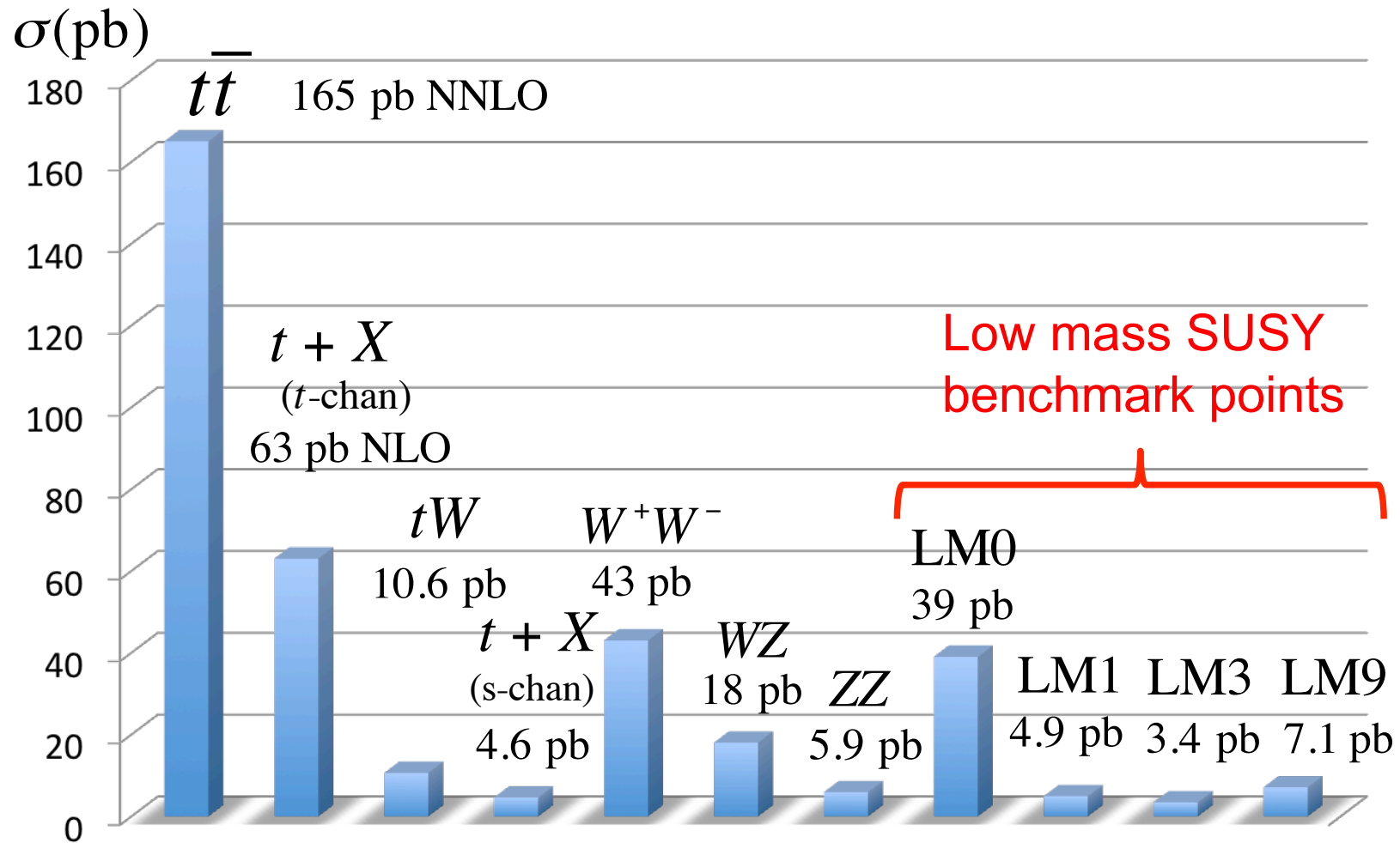
- Look for delayed gluino decays during periods of no beam including

- inter-bunch gaps
- no-beam periods

- Result from 30 days running at  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$



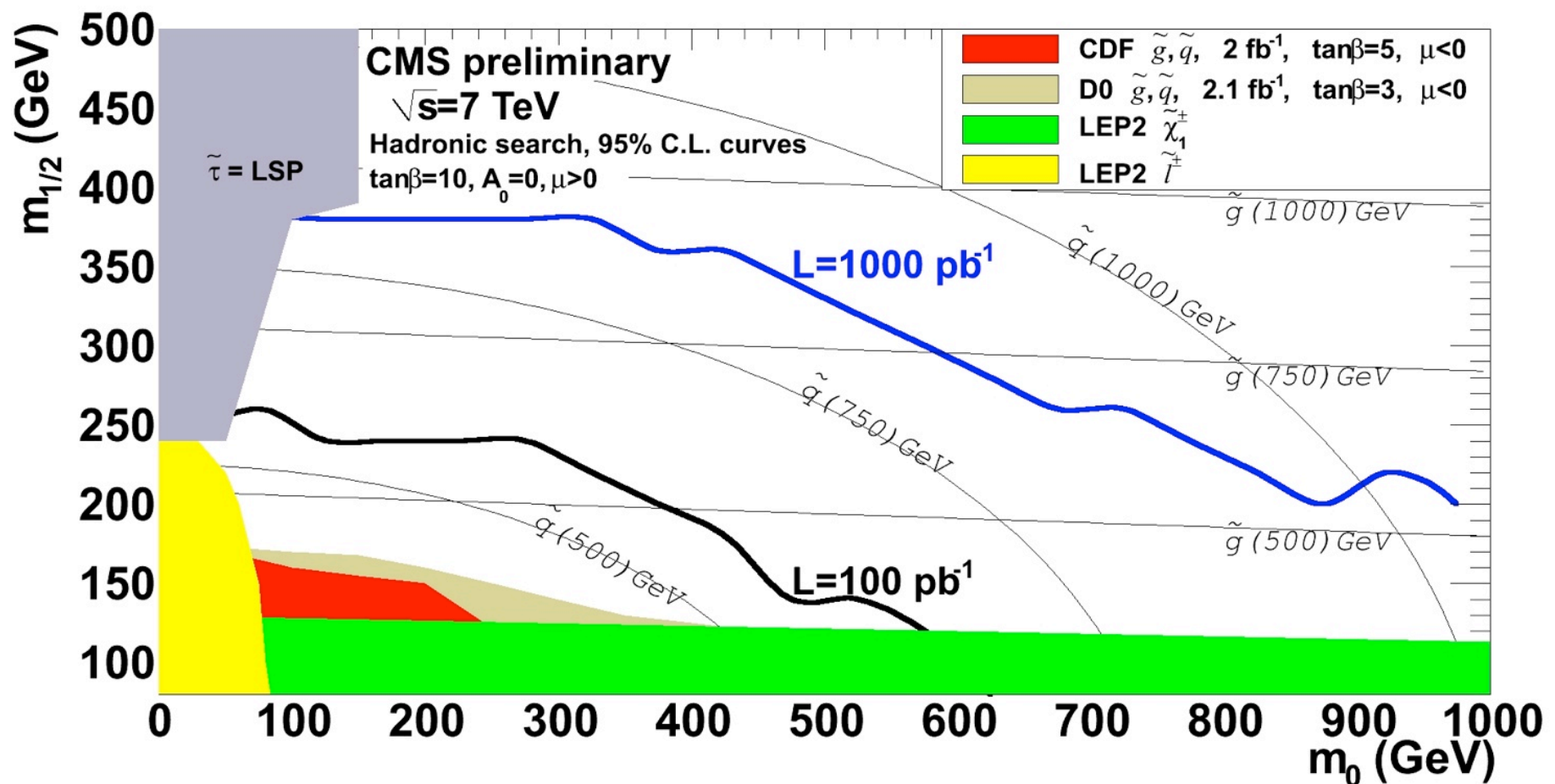
# Benchmark SUSY v. SM cross sections



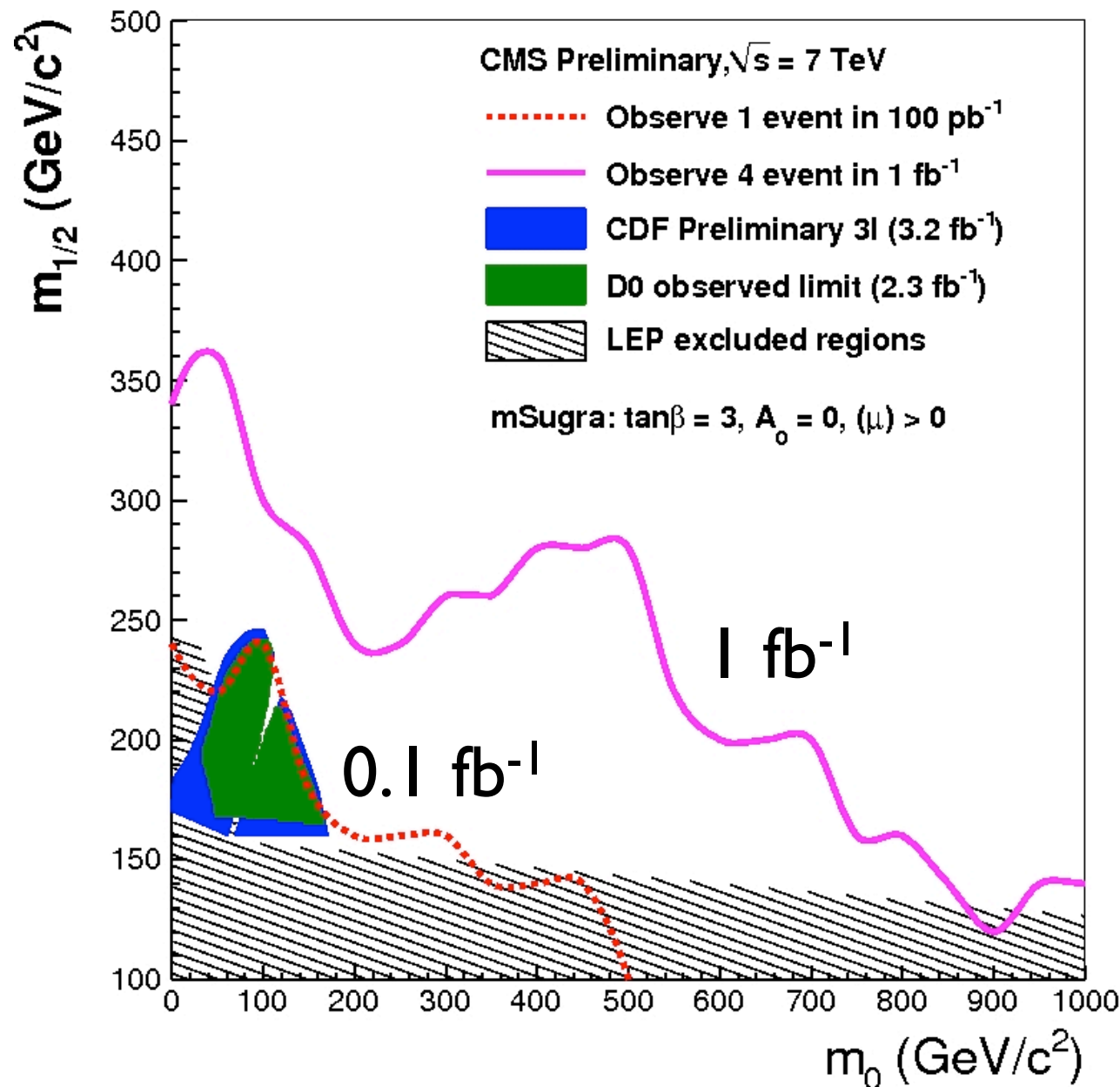


# SUSY: Jets + missing $E_T$

- “Classic” all-jets search:
- 3 or more jets,  $E_T > 50$  GeV
  - missing  $E_T > 250$  GeV
  - no leptons

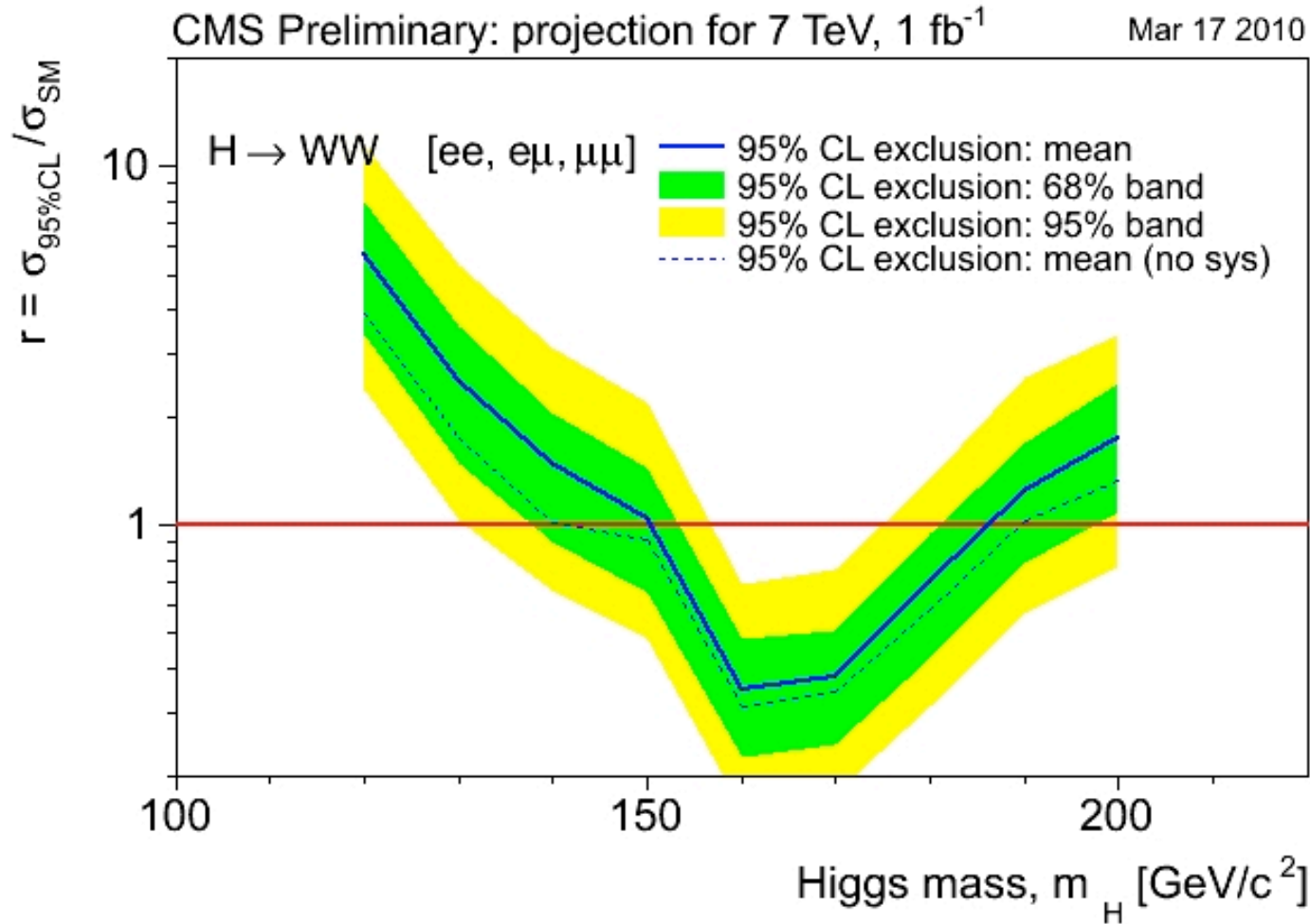


# SUSY: like-sign dileptons



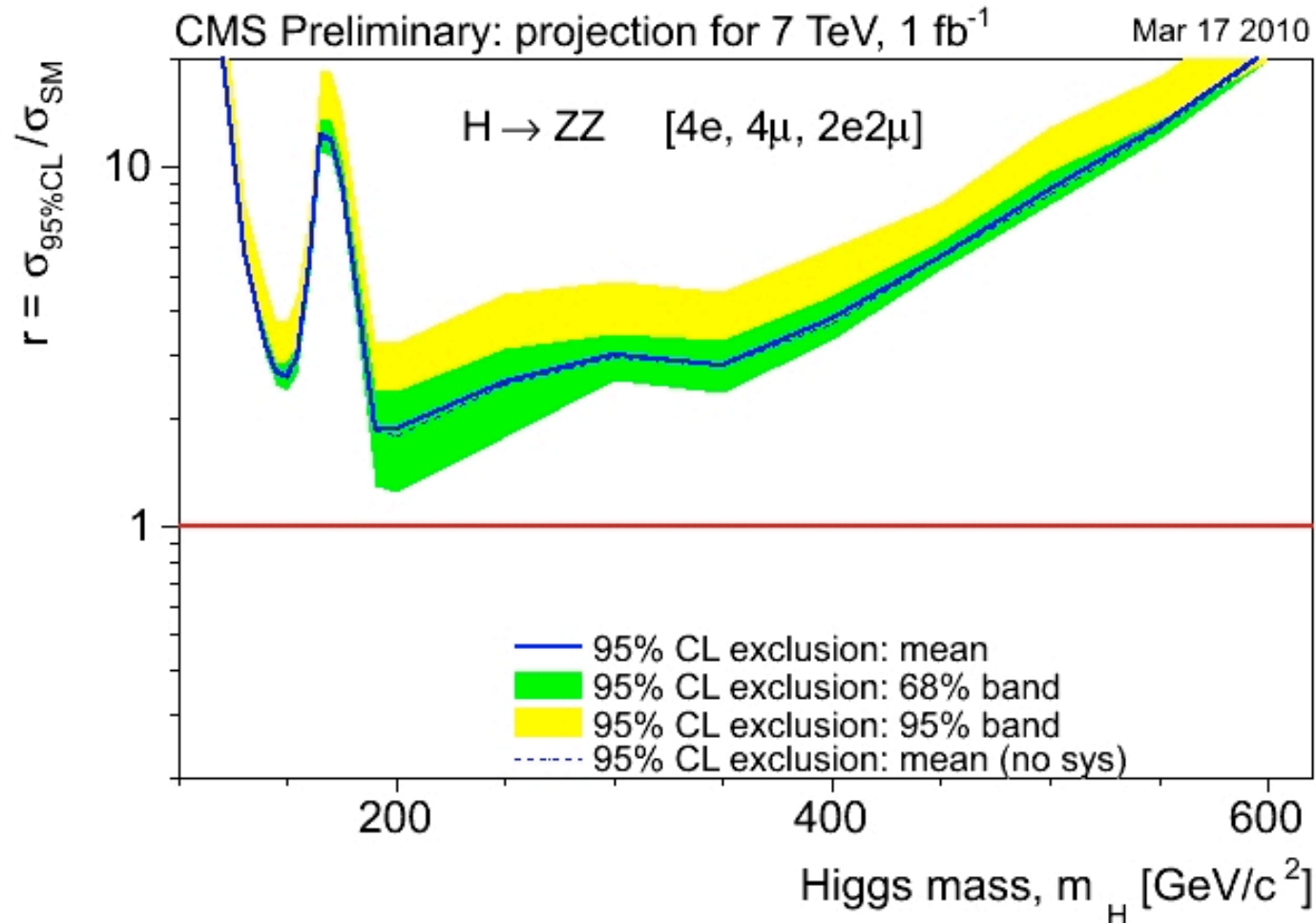
Very soon the  
LHC will  
surpass the  
Tevatron in  
the search for  
SUSY

# Standard Model Higgs: $WW \rightarrow 2\ell 2\nu$



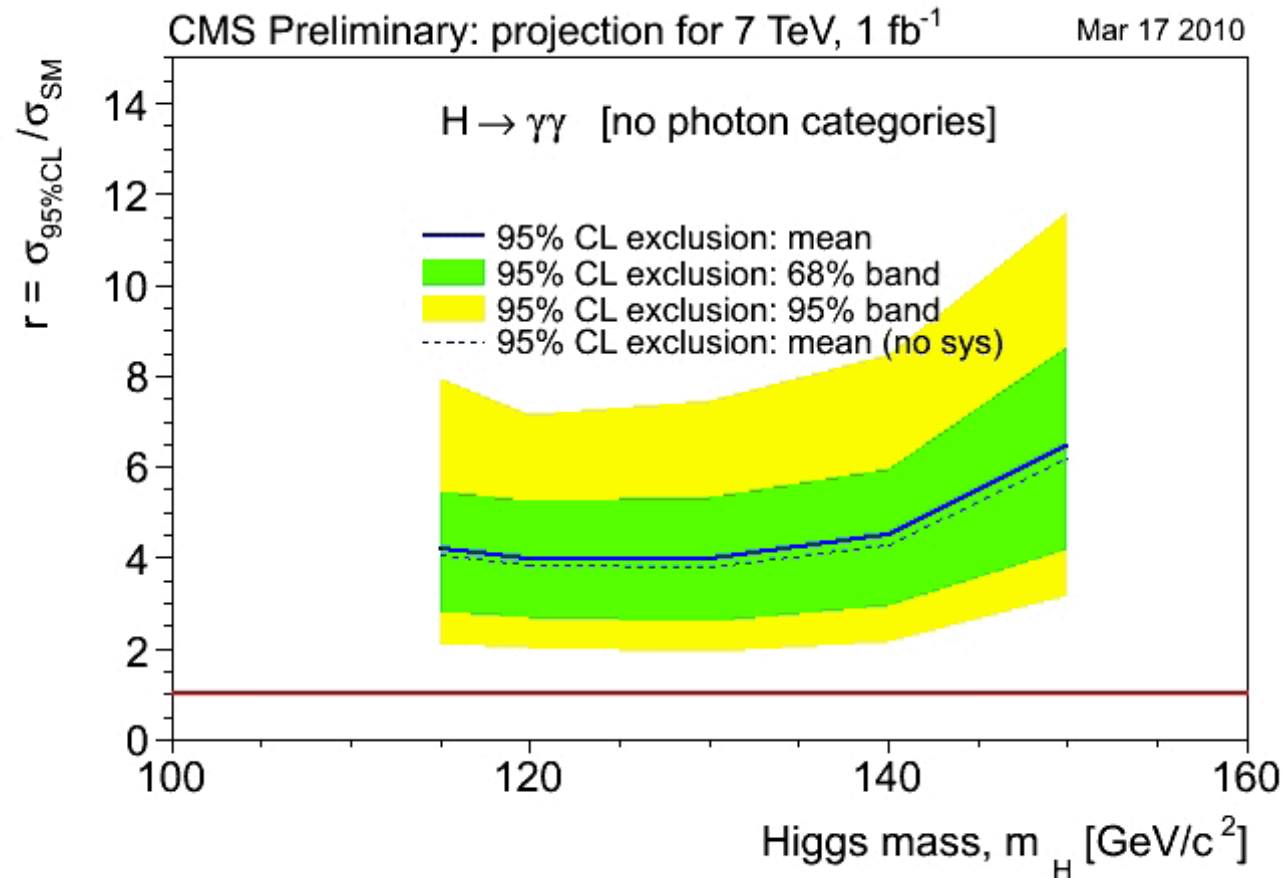
High mass has greater sensitivity. Yet no discovery of SM Higgs in 7 TeV run. With 1 fb<sup>-1</sup>, similar to Tevatron.

# Standard Model Higgs: $ZZ \rightarrow 4\ell$



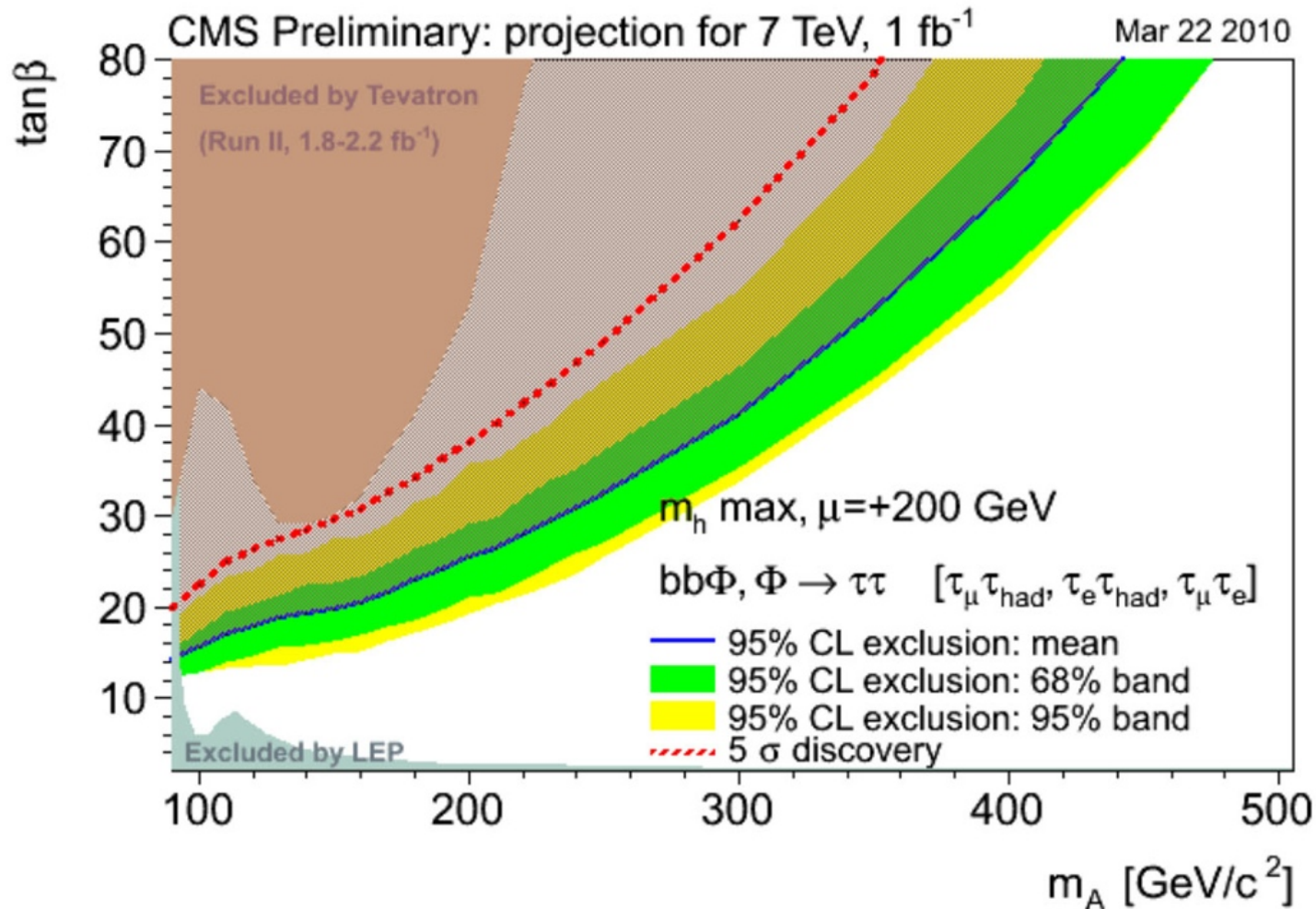
$H \rightarrow ZZ$  has sensitivity going to much higher masses.

# Standard Model Higgs: $H \rightarrow \gamma\gamma$



No exclusion of low mass SM Higgs  
anticipated in with 1 fb<sup>-1</sup> at 7 TeV.

# MSSM Higgs



Di-tau sensitivity for H/A will soon exceed Tevatron.



# Expected Luminosity in Coming Years

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	6	3.5	2.5	7 e10	720	1.0 e32	-	0.1	0.1
2011	9	3.5	2.5	9 e10	720	2.0 e32	0.1	1	1.1
2012	18-month stop for splice solution and retraining (partial), re-arrange DS for cryo collim								
2013	6	6.5	1	9 e10	720	9 e32	0.45	2.7	3.8
2014	9	6.5	1	9 e10	1404	1.7 e33	0.6	5.3	9.1

--- 8-month stop for collimators phase 2 (remove RPs) + train to 7 TeV

2015 (Aug-Nov): 7.0 TeV 8.0 / fb up to 2808 bch \* 9e10 @ 1.0 m (up to 3.6e33)

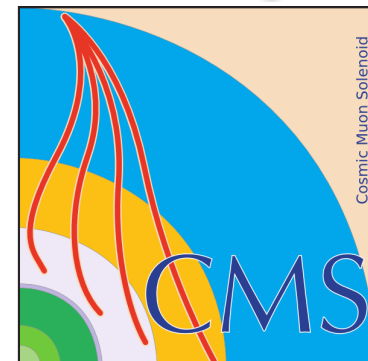
2016 (Feb-Oct) : 7.0 TeV 29.0 / fb up to 2808 bch \* 9e10 @ 0.55 m (up to 6.2e33)

# CMS Physics Public Results...

- Underlying Event in proton-proton collisions at  $\sqrt{s} = 900$  GeV (published)
- Measurement of Bose-Einstein Correlations with first CMS data (submitted to journal)
- Two-particle correlations and cluster properties from two-particle angular correlations
- Transverse-momentum and pseudorapidity distributions of charged hadrons (submitted)
- Muon charge asymmetry in cosmic data

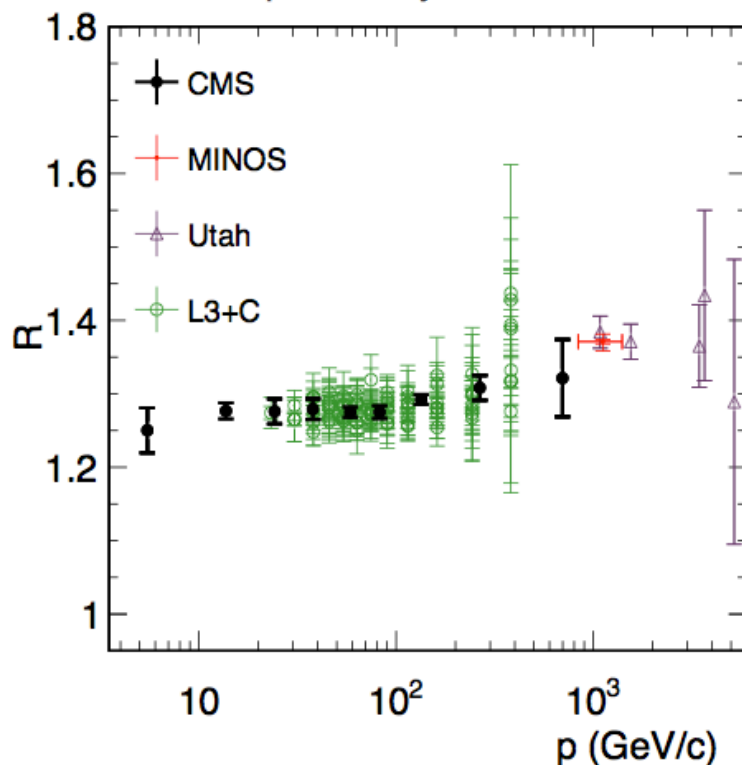
# New: Muon Charge Asymmetry

- Cosmic data from '06, '08, '09: first measurement of a physical quantity from CMS.
- Results agree with other expts; provided useful alignment and calibration experience.

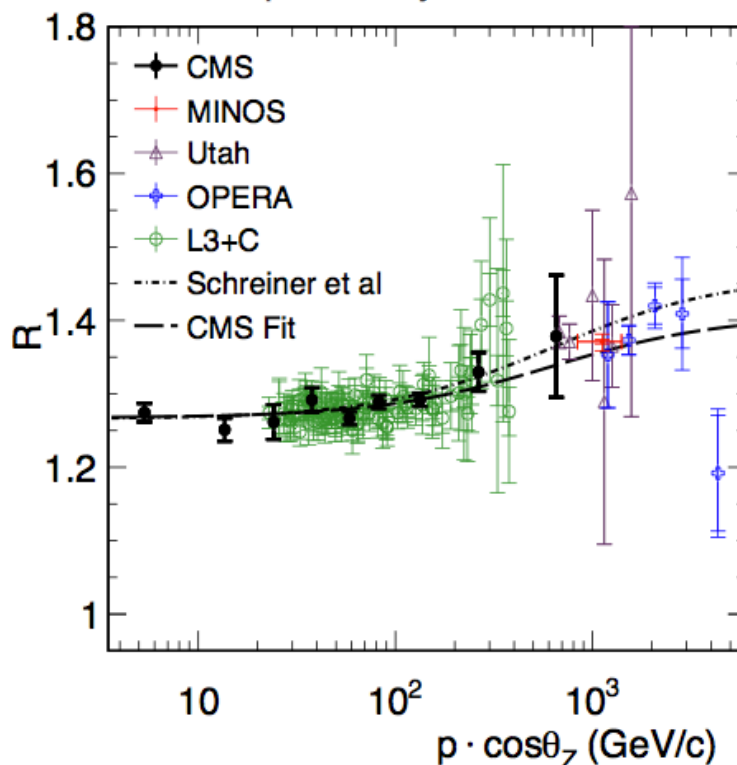


$$R = N_{\mu+} / N_{\mu-}$$

CMS 2006-2008 preliminary

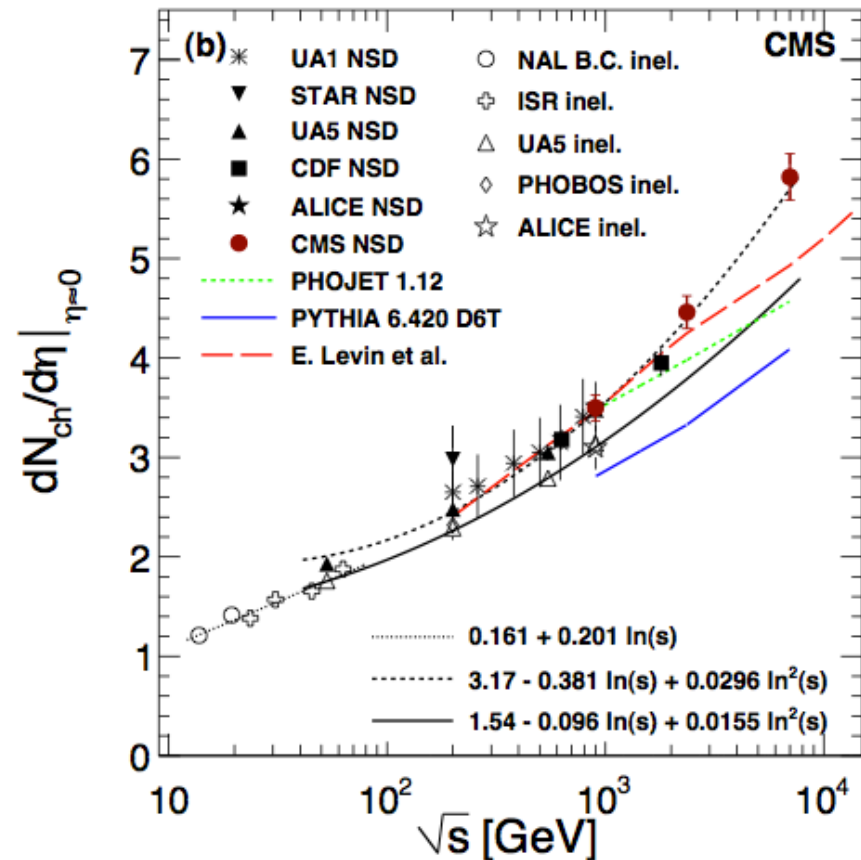
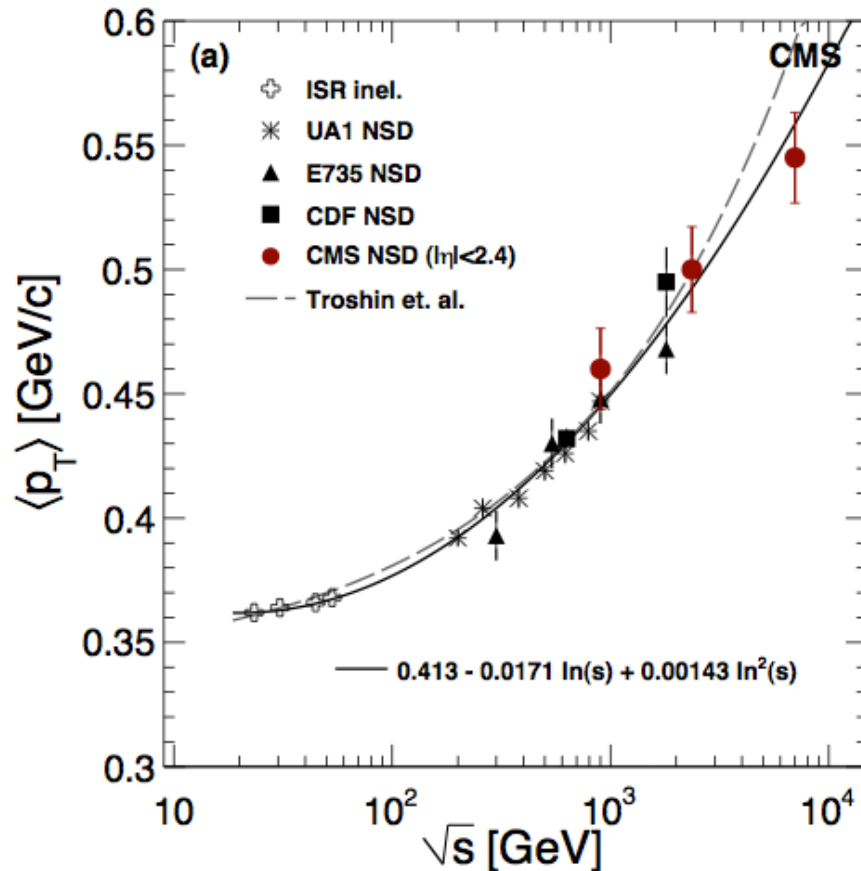


CMS 2006-2008 preliminary

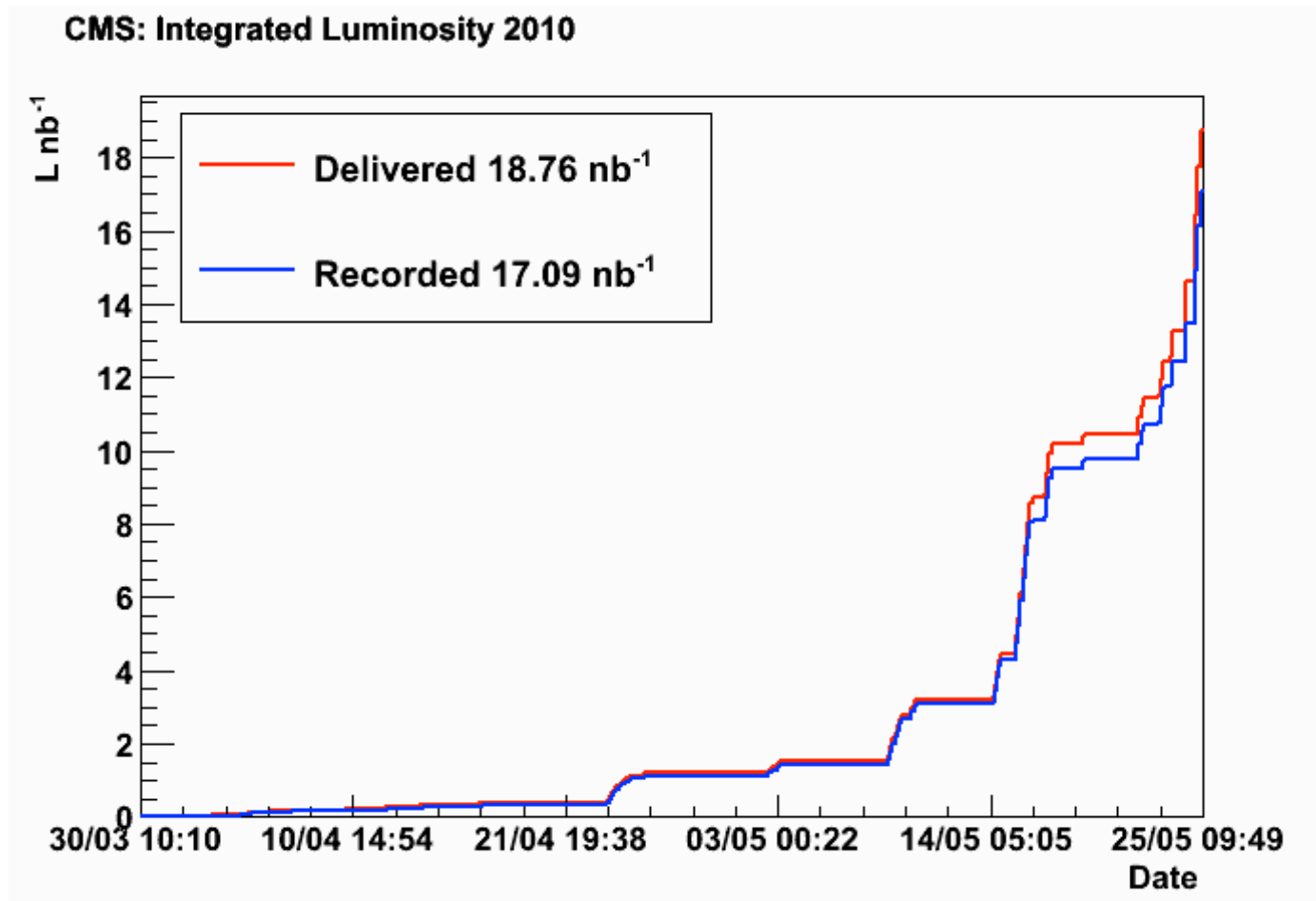


# New: Charged Hadrons

- $p_T$  and  $\eta$  distns of charged hadrons at 7 TeV:  
Important in understanding isolation in events.
- Rise of particle density stronger than current models.



# Integrated luminosity: update today!

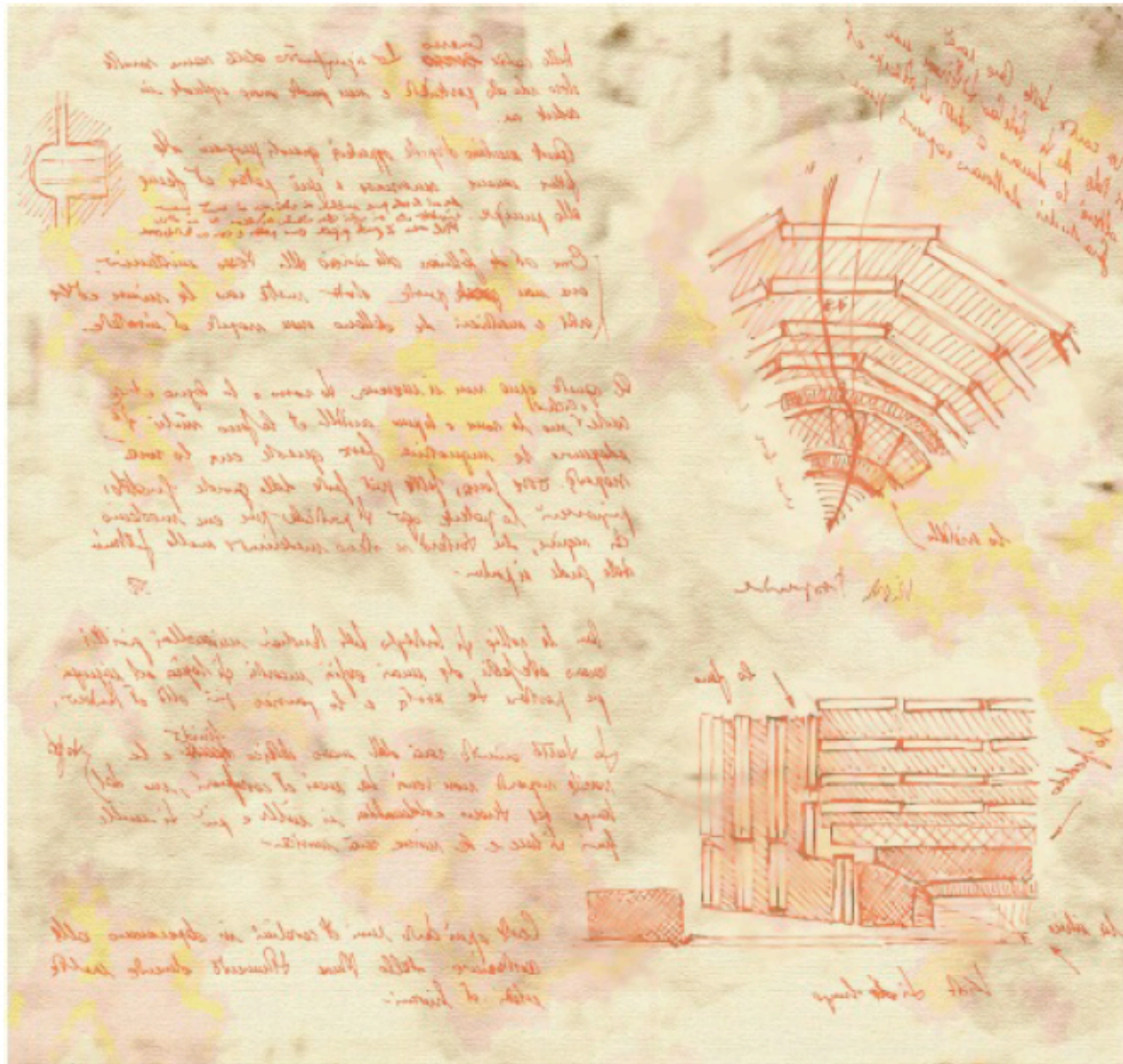


Last night's store almost doubled our delivered dataset... Data are starting to come at a faster pace!



# No longer just a sketch...

CMS technical proposal in style of Leonardo da Vinci





# Look for the Revolution to come!



John the Baptist

-da Vinci